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~~This volume~~ presents the text of a study which attempts to define the air pollution problems of the iron foundry industry and to set priorities for research and development activities that will lead to improved emission control capabilities at reduced cost. The following areas are covered extensively: foundry emissions produced and control capability thereof; the quantification and evaluation of emissions; technical and economic analysis of emission control technology; technical and economic analysis of potential modifications to foundry processes and equipment; projection of trends; and recommended research and development. ~~Volume II of this study contains exhibits and volume III consists of six appendices.~~

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SYSTEMS ANALYSIS OF EMISSIONS AND EMISSIONS CONTROL IN THE IRON FOUNDRY INDUSTRY

VOLUME I TEXT
FEBRUARY, 1971

For

Division of Process Control Engineering
Air Pollution Control Office
Environmental Protection Agency
Contract No. CPA 22-69-106

Prepared by
A. T. Kearney & Company, Inc.
Chicago, Illinois

AIR POLLUTION CONTROL OFFICE

SYSTEMS ANALYSIS OF EMISSIONS AND EMISSIONS CONTROL IN THE IRON FOUNDRY INDUSTRY
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D	Detail Economic Cost Curves
E	Emission Test Procedures
F	Glossary of Terms

NATIONAL AIR POLLUTION CONTROL OFFICE

CONTRACT NO. CPA 22-69-106

SYSTEMS ANALYSIS OF EMISSIONS AND EMISSIONS
CONTROL IN THE IRON FOUNDRY INDUSTRY
VOLUME I TEXT
FEBRUARY, 1971

I - INTRODUCTION

ACKNOWLEDGEMENTS

A. T. Kearney & Company, Inc. gratefully acknowledges the many people and organizations who cooperated and assisted in this study.

We acknowledge the cooperation and assistance provided by the American Foundrymen's Society and the Gray and Ductile Iron Founders' Society in furnishing information and in obtaining the cooperation of their member foundries. In addition, A.F.S. provided the use of its headquarters for review meetings with the Industry Liaison Committee.

We acknowledge the assistance provided by the members of the Industry Liaison Committee who were helpful in reviewing the progress of the study and providing a critique of the report.

We acknowledge the assistance and cooperation of the many iron foundries who provided A. T. Kearney & Company the courtesy of plant visits and furnished data for this study and for the data bank.

We acknowledge the assistance and cooperation of the various manufacturers of foundry equipment and the manufacturers of

emission control equipment for providing valuable technical and economic data.

Finally, we thank the staff of APCO for their assistance and guidance.

This report was prepared by a project team of A. T. Kearney staff and associated consultants. The overall direction was under Mr. E. Stuart Files, Vice President of A. T. Kearney & Company, Inc. The Project Director was Mr. Joseph H. Greenberg, Principal, and the other members of the team were Mr. Robert E. Conover, Senior Associate; Mr. Bernard Gutow, Associate; and other members of the Kearney Organization. The associated consultants who provided valuable assistance in carrying out of the work were Mr. John Kane, Mr. George Tubich, and Mr. James Ewens, all independent consultants in air pollution control and foundry operations.

PURPOSE OF THE STUDY

The Air Pollution Control Office has the task of developing technology for a national program for control of air pollution and, as a part of this program, is conducting a series of systems analysis studies of various industries. These studies are being conducted by the Division of Process Control Engineering. This study is directed at the iron foundry industry, with particular emphasis on the melting area. The primary goal of the study is to define the air pollution problems of the iron foundry industry, and to set priorities for research and development work that will lead to improved emission control capabilities at reduced cost.

SCOPE OF THE STUDY

For the purposes of this study, the iron foundry industry was defined as those shops that melt iron (including iron and steel scrap) in furnaces, pour the molten iron into molds, and alloy and/or treat the iron in either the molten or cast state, with processes limited to making gray, malleable, and ductile cast iron. This definition excludes blast furnace processes, including direct casting of blast furnace metal into molds, and processes for converting iron to steel.

The following iron foundry facility and operations areas were included in the study:

1. Raw materials receiving, storage, handling, preparation, and charging.
2. Iron melting, duplexing, holding, desulphurization, inoculation, and magnesium treatment for producing ductile iron. Equipment includes cupolas, direct and indirect electric arc furnaces, coreless and channel induction furnaces, stationary and rotary fuel fired furnaces, inoculation and magnesium treatment units.
3. Sand molding, pouring, cooling, shakeout, sand handling, storage, preparation, and distribution.
4. Casting cooling, cleaning, grinding, heat treating, and painting.

5. Coremaking of oil-bonded, chemically bonded, and other types of cores.

6. Other auxiliary areas in the iron foundry that produce emissions.

LITERATURE SEARCH AND BIBLIOGRAPHY

An extensive search of the literature was conducted to identify and list in a single bibliography published material pertinent to the subject of this study. During the course of this literature search, approximately 191 information sources, including serial publications, have been identified.

A total of 735 references of related material were cataloged, including 511 articles in technical journals, 213 books, and miscellaneous publications by industry, technical societies, and governmental bodies, plus 11 patents.

Appendix A is a copy of the bibliography which is arranged by calendar year and subdivided into categories of books, reports, and articles.

GLOSSARY OF TERMS

Standard iron foundry industry and air pollution terminology are used throughout this report. Definitions of these terms are provided in Appendix F, Glossary of Terms, found in Volume III of this report.

II - SUMMARY AND RECOMMENDATIONS

SCOPE AND OBJECTIVES

The Air Pollution Control Office has the task of developing technology for a national program for control of air pollution and, as a part of this program, sponsored a series of systems analysis studies of various industries which are primary sources of air pollution. This study was directed at the iron foundry industry, with particular emphasis on the melting area, and was conducted by A. T. Kearney & Company, Inc.

The primary goal of the study was to define the air pollution problems of the iron foundry industry, and to set priorities for research and development work that will lead to improved emission control capabilities at reduced cost.

DESCRIPTION OF THE IRON FOUNDRY INDUSTRY

The number of gray, malleable and ductile iron foundries in the United States has decreased from about 3,200 in 1947 to 1,670 in 1969, with a trend of reducing by about 70 installations per year. These foundries are located in 48 states, although 80% are located in only 13 states. Of all iron foundries, only about 525, or 29%, can be classified as medium and large foundries, employing more than 100 people, and only 91 can be called very large.

The cupola is still by far the most common method of melting iron, with about 1,970 cupolas in service in 1970. This is a decline of 2,500 in the past 25 years. This decline can be expected to continue, as more foundries are closed, and others convert from cupola to electric melting. Electric arc installations are increasing rapidly as are electric induction installations.

The information available regarding the other productive operations in iron foundries which are sources of emissions is not nearly as well documented as the melting area. However, we know that all foundries employ some kind of molding practice, with most iron foundries using sand molding. The modern trend is toward automated or semiautomated molding, employing conveyors of some type for moving molds past each of the stations. This can be expected to increase as more foundries automate or mechanize their operations.

Coremaking is another area that is undergoing rapid changes, with the trend being away from oil-bonded, baked sand cores, toward chemically bonded, thermally cured cores.

The widespread distribution of iron foundries, and the prominence of the cupola stack in most communities in which an iron foundry is located, have combined to label the iron foundry as a major source of air pollution. It has been estimated that iron foundries produce 243,000 tons of particulates in the United States each year. Although some of these are now captured by the presently used emission control equipment, a large percentage is being discharged to the atmosphere, equal to about 0.9% of all particulate matter emitted by all sources.

The pollutants discharged by the iron foundry industry can be classified as:

1. Emissions from melting furnace operations.
2. Emissions from other dust-producing operations within the plant.
3. Odors and gaseous compounds from both sources.

EMISSIONS PRODUCED AND CONTROL CAPABILITY

Processes in the iron foundry can be divided into six production areas:

1. Raw material storage, preparation and charging.
2. Metal melting.
3. Molding, pouring and shakeout.
4. Sand conditioning and reclamation.
5. Cleaning, heat treating and finishing.
6. Coremaking.

Each operation contains equipment and processes capable of producing air pollutants in the form of noxious fume, and/or particulate matter. The latter ranges from metal dust from grinding operations, that is relatively easy and inexpensive to control, to extremely fine ferrous and nonferrous oxides and smoke from melting furnaces that are very expensive and difficult to control.

Over the years, increasing attention to foundry and other industry sources of pollution has prompted development of numerous methods and techniques for control of emissions from these sources.

Of all techniques available to control foundry pollutants, emission collection equipment systems are the most significant. These systems, which include dry centrifugals, wet collectors, fabric filters and electrostatic precipitators, vary widely in design, capabilities, cost and application.

QUANTIFICATION AND EVALUATION OF EMISSIONS

Although the majority of gray iron foundries currently do not have collection equipment systems for control of emissions from melting operations, the number of installations of these systems has increased rapidly the last few years.

By far the majority of the foundries use cupolas, with only about 15% of production made using other forms of melting. The major components of particulate emissions from iron melting cupolas can be grouped into three major categories: (1) metallic oxides (2) silicon and calcium oxides, and (3) combustible materials.

The amounts of metallic oxides occurring in cupola emissions are related to the presence of the respective metals in the scrap charge and their partial vapor pressures at the temperature of the cupola melting zone.

The oxides of silicon and calcium, representing the second category, result from lining erosion, embedded molding or core sand on foundry returns, dirt from the scrapyard adhering to scrap, or from the limestone flux.

The third category of emissions, combustible material, includes coke particles, vaporized or partially burned oil and grease and other contaminants swept up the stack by the top gases.

The effects of 15 variables on the type and quantity of cupola emissions have been evaluated by the use of a variety of analytical techniques. The analyses demonstrate that some of the variables have strong and quantifiable effects and others have insignificant effects on emission levels.

Although the cupola has been considered to be the principal source of iron foundry emissions which are difficult or costly to control, there are other areas in the foundry which also produce these types of emissions. Some of these have been adequately and economically controlled with existing designs of equipment, while others have proven to present problems which have not yet been completely solved.

The ease and cost of controllability can generally be related to two broad aspects: the problems which relate to capturing the emissions with a minimum of infiltrated air and the problems of adequately removing the offending fine particles and gases from the captured effluents before releasing them to the atmosphere. In general, those operations which in many foundries take place in open, nonconcentrated, nonstationary locations are difficult to control although in many cases, the actual costs of control may not be high once the effluents are captured. Such operations occur in the scrapyard, mold pouring area, and the shakeout area.

The other areas which involve difficulty of capture and high cost of control equipment include melting, inoculation and coremaking.

TECHNICAL ANALYSIS OF CONTROL TECHNOLOGY

A detailed analysis was presented of each of the types of emission control equipment in use in each of the areas of the iron foundry. This included a description of the equipment, its application, historical background, and its relative position as compared with other equipment. Case histories of past attempts to abate emissions were cited. In general, it was demonstrated that equipment and methods exist for control of almost all foundry emissions, although in many cases the economics are unfavorable, particularly for small foundries.

ECONOMIC ANALYSIS OF CONTROL TECHNOLOGY

Estimates have been made of the capital costs and annual costs of operation of control systems based upon analysis of existing and proposed installations. The cost data obtained were all basically for foundries with cupolas controlled with wet caps, mechanical collectors, fabric filters, and high and low energy wet scrubbers, and for electric arc furnaces controlled with fabric filters.

The major factor that influences capital cost is the type of melting equipment. The complexity of control systems is greatest for the cupola, moderate for the electric arc, and least for induction melting.

A number of design and operating variables are related to the total cost of emission control systems. These include melt rate of the furnace, pressure drop of the system, blast volume in standard CFM and gas volume throughput in actual CFM. A computerized multiple regression analysis of the collected data has confirmed that total costs varied most directly with actual gas volume throughput.

A comparison of the impact of annual costs was made for wet scrubbers and fabric filters. These were the more popular and commonly used types of control systems observed on foundry melting equipment. These operating costs were given in terms of cost per ton of metal melted for wet and dry collectors on cupolas and arc furnaces.

A series of model foundries developed as a means of relating the economics of emission control installation and operation to the total costs of installing and operating iron melting departments. These models covered the complete melting department of foundries with melting capacities of 5, 15, 30 and 50 tons per hour, and operating at varying levels, including 500, 1,000, 2,000 and 4,000 hours per year. Melting methods included cupola, arc furnace and induction furnace. Costs of emission control installation and operation were identified as a percentage of total costs for each of these conditions.

POTENTIAL MODIFICATIONS TO FOUNDRY PRACTICES AND EMISSIONS PRODUCING AND CONTROL EQUIPMENT

Of all foundry operations causing emissions to be released to the atmosphere in some degree, the melting operation has received the greatest attention. The effort to improve collection capability of a lower cost has been concentrated on the problem of the cupola as the source of the greatest amount of particulate matter. The results of these investigations in recent years have been a number of modifications offering at least a partial solution to the problem.

Other work has been done in the areas of preheating, magnesium treatment for producing ductile iron, pouring and cooling, sand handling and coremaking.

Cupolas and cupola operations can be modified in an attempt to achieve two goals: to decrease the cost of emissions collection and to decrease the quantity of emissions requiring collection. One method of decreasing the volume of cupola stack gas is to limit air infiltration by reduction of the charging door area. Locating the gas take-off below the top of the charge burden is a second method of reducing air infiltration and thereby decreasing the volume of gas to be cleaned.

Reduction of coke in cupola charges offers some beneficial results. The evaluation of cupola emissions indicates that particulate emissions tend to decrease as the amount of coke in the cupola charge decreases. Heating of the cupola blast air has been recognized for many years as one method of increasing the melting rate with the same coke charge or of maintaining the melting rate with a smaller coke charge. Oxygen enrichment of the blast air also results in a decrease in coke requirements by reducing the 80% nitrogen in air which would otherwise require heating to the iron melting temperature in the cupola. Natural gas injection, like oxygen enrichment, provides a means by which cupola coke requirements can be reduced, melting rate increased, melting costs lowered, and a modest decrease in particulate emissions can be realized.

Screening of limestone and coke before loading into the charging bucket is an elementary and inexpensive step to prevent breeze and dust from being charged into the cupola. Scrap preparation is more often performed by scrap dealers than foundry personnel due to the equipment cost and labor requirements. An increasing amount of today's scrap is automotive, consisting of whole or broken engines or fragmented bodies.

The increase in the number of electric and reverberatory melting furnaces in recent years, at a time when the number of iron foundries have decreased dramatically, is evidence that one acceptable solution to the problem of the high cost of emissions control is to replace the cupola by a furnace that produces less emissions. Installation and melting costs of alternative furnaces are not always lower, but the total of the advantages sometimes tips the scale in favor of cupola replacement.

Improvements in emissions control equipment in the foreseeable future, with few exceptions, promise to be minor in nature. These will be results of efforts by the manufacturers of this equipment to improve quality of manufacturing, use of better materials and redesign to raise efficiencies and lower costs of their products.

PROJECTION OF TRENDS

Total iron castings production, excluding ingot molds made from direct blast furnace iron, has been projected to be approximately 17 million tons per year by 1980, or an average 2% increase per year.

The number of foundries which will be in operation by 1980 has been projected to be approximately 1,100. Since the number of medium- and large-sized foundries has been projected to increase slightly, the entire drop from the 1969 total of 1,630 foundries to 1,100 foundries is expected to take place among the small-sized companies. The combination of increasing output and reduced number of producers is expected to continue to increase the average output per foundry to an estimated 16,500 tons per year by 1980.

The most significant changes in the types and uses of equipment which are expected to take place in the iron foundry are in the melting department. The cupola, which once was almost the only source of molten iron, has been rapidly declining in number of installations, with the number in 1969 being only about 45% of those in existence immediately after the war. This decline has been projected to continue at an undiminished rate, with the number of cupolas in 1980 estimated to be about 1,300.

In 1969, an estimated 85% of all iron melted in iron foundries was performed in cupolas. As the replacement of cupolas by other forms of melting continues to accelerate, the amount of iron melted in cupolas will decrease, with the amount by 1980 projected to be as low as 50% of the total. The electric methods of melting, both direct arc and induction, will account for almost 50%, with the small remainder being melted in fuel fired, reverberatory furnaces.

The tonnage of malleable iron which is produced is expected to remain relatively constant. On the other hand, the tonnage of ductile iron has been increasing every year and is expected to be about double the 1969 tonnage by 1980. This will result in a corresponding increase in the amount of magnesium treatment of iron which will be performed.

The trend toward mechanization of molding, pouring and shakeout lines has been continuing at an increasing rate. There is every reason to believe that within the next 10 years, the majority of iron foundries will use some form of mechanized molding, pouring, shakeout and sand preparation.

Coremaking has also been undergoing a technological change, with the trend being away from oil-bonded, baked sand cores, toward chemically bonded, thermally cured and air cured cores.

The entire area of handling and preparation of materials used in the foundry is continually being reviewed with respect to the effect on emissions production and economy of collection. Iron foundries are being more selective in purchasing of scrap, with more attention being given to elimination of combustible materials from the scrap before purchase. Larger foundries are installing scrap preparation facilities involving pre-burning or cleaning to remove materials which will produce emissions during melting.

Many of the trends toward electric or fuel fired melting furnaces, mechanized molding, and continuous sand preparation systems will have important effects in reducing the quantity of emissions produced, or in making the emissions easier or less costly to collect. The decisions made in selecting new equipment are, therefore, being made to an increasing degree with reference to the effect on reduction of emissions, or on economy of emissions collection.

The use of a greater amount of pre-cleaned or burned scrap will reduce the quantity of emissions from combustibles now charged into furnaces along with the scrap. The trend away from cupola melting and toward electric or fuel fired melting furnaces will have a significant effect in reducing emissions.

The mechanization of molding, pouring, shakeout and sand preparation facilities has not reduced the quantities of emissions which are produced, but has resulted in confining their production to fixed locations. Thus, it is relatively simple in many cases to construct enclosures which can be used as a means of collection of emissions with a minimum of infiltrated air.

DEFINITION OF IRON FOUNDRY AIR POLLUTION PROBLEMS

The principal areas in which emissions which are difficult or uneconomical to collect in the iron foundry have been identified as iron melting, particularly in the cupola, and in coremaking. Particulate emissions from all iron melting operations have been estimated to total 243,000 tons per year, of which approximately 182,000 have been estimated to be discharged to the atmosphere. Emissions from each foundry source were evaluated with regard to variables of quantity, particle size, difficulty of collection, availability and cost of equipment, economics, and reliability of equipment. A rating system was developed to identify the areas of highest priority with regard to additional development work required.

RECOMMENDED RESEARCH AND DEVELOPMENT

The gaps between existing knowledge, equipment and techniques and the necessary levels required to efficiently and economically control emissions in the iron foundry were identified in the areas of fundamental knowledge, economics, materials, and processes. Ongoing research and development in these areas was identified, as far as information was available. A group of 10 research and development projects was recommended to bridge the gap between existing and required technology. For each of these projects the goals, procedure, estimated time and costs, and priorities were developed. The recommended projects are summarized as follows:

No. 1. Controlled stack sampling program of emissions from cupolas to determine effects of design and operating variables on the quantity and type of emissions.

No. 2. An extension of Project No. 1 to provide quantitative data on effect of variables on iron oxide formation in the cupola.

No. 3. An extension of Project No. 1 to provide data on relationship between quantity of fine metallic oxides in cupola gases and opacity of stack plume.

No. 4. Development of fabric materials for fabric filters, which will be resistant to high temperatures and corrosive gases.

No. 5. Development of improved means for efficient utilization of sensible heat and heat of combustion of cupola stack gases.

No. 6. Development of continuous iron melting furnace as a replacement for the cupola, using fuel firing or electric power for economical, low emission melting.

No. 7. Development of economical, centralized scrap preparation facilities to serve iron foundries.

No. 8. Development of core binder materials with low level of acrid or noxious gas evolution during curing.

No. 9. Development of sonic or other method of agglomeration of fine particles to make them easier to collect.

No. 10. Development of uses for waste products from iron foundry melting operations.

III - AIR POLLUTION AND THE IRON FOUNDRY INDUSTRY

DESCRIPTION OF THE IRON FOUNDRY INDUSTRY

Iron Castings Production

Annual castings production in the United States has varied widely, depending on the economy, with the ranges during the postwar period as follows:

Iron Foundry Production [1, 2]

	Production Tons per Year		
Type of Metal	Minimum	Maximum	Last 5-Year Average
All Metals	13,200,000	20,800,000	20,000,000
All Reported Cast Iron	11,032,000	17,084,000	16,329,000
Cast Iron from Iron Foundries	10,000,000	14,486,000	13,817,000
Gray Iron	9,340,000	11,936,000	11,650,000
Malleable Iron	661,000	1,227,000	1,075,000
Nodular Iron	-	1,570,000	1,092,000

The complete castings production picture has been shown graphically in Exhibit III-1. The data, as reported by the Department of Commerce, included the production of ingot molds. However, only about 30% of ingot molds are produced from gray iron melted in cupolas, with the rest being produced from direct blast furnace metal. Since castings production from direct metal was excluded from this study by definition, and additionally has already been covered by the iron and steel industry study, the estimated portion of ingot mold production produced from this source was deducted from total iron castings production.

Iron castings produced in foundries have accounted for approximately 69% of total weight of castings production from all metals. Nonferrous metals have accounted for approximately 8%, steel castings were approximately 10%, and ingot molds from blast furnace iron accounted for the remaining 13%. From these figures, it is evident that iron castings are by far the most important classification of metal cast on a tonnage basis. The rate of increase of iron castings production has been found to be closely related to three industries--steel, construction and automotive. Ingot mold castings production amounts to approximately 8% of iron foundry production and varies with steel industry production rates. Pressure pipe, soil pipe and fittings production amount to approximately 20% of total iron foundry production and varies with domestic, industrial and public construction levels. Miscellaneous castings production covers the balance of 72% of iron foundry output and varies most closely with automotive, truck, bus, and agricultural vehicle production. This last item includes gray iron, ductile iron and malleable iron castings.

Iron Foundry Population

The population trends in the foundry industry have been developed in Exhibit III-2. The total number of foundries of all types has remained relatively constant during the postwar period, ranging from 5,000 to 5,800 and averaging approximately 5,400. However, the iron foundry population has shown a steady decline, from 3,200 in 1947, to 1,670 in 1969. If this decline continues, the number of iron foundries is projected to be approximately 1,100 by 1980. However, the average size of iron foundries has been increasing steadily, with average annual production per foundry going from 3,800 tons in 1947, to 5,300 tons in 1959, and to 8,700 tons in 1969. By 1980, the average production per iron foundry is projected to be approximately 16,500 tons per year.

An analysis of the population of iron foundries with respect to size of foundry has shown that almost the entire decline in foundry population has been among the small foundries, with employment of under 100 per foundry. The number of medium-sized foundries has remained almost constant, while the number of large foundries has increased slightly. The number of small foundries had declined by one-third from 1959 to 1969, and is expected to further decline to only about half of the 1969 population by 1980.

Geographical Location of Iron Foundries

The distribution of iron foundries by states and by major metropolitan areas is shown in Exhibit III-3. The highest concentration is in the states which border on the Great Lakes, namely, Pennsylvania, Ohio, Michigan, Illinois, Wisconsin, New York and Indiana. This group of seven states contains almost half of all of the iron foundries in the United States and more than half of the iron castings capacity. The State of California contains the greatest concentration of iron foundries in the western half of the country, with one-third of the iron foundries in that 17-state area being in California. Other areas of high iron foundry concentration are in the southeastern states and in the northern states bordering on the west bank of the Mississippi River.

The location of the principal concentrations of iron foundries has been pinpointed into major metropolitan areas. A total of 50 such areas accounts for more than two-thirds of the iron foundries. Here again, the principal concentration is in the industrial cities in the seven Great Lakes states, with two-thirds of these centers being in, or bordering on, those states. It is of further interest to note that the decline in number of iron foundries in these areas was a considerably lower rate than for the balance of the country, emphasizing the fact that the greatest mortality in iron foundries has been among the smaller companies located in the smaller metropolitan areas.[1]

The variations which have occurred in the distribution of iron foundries by states during the period of 1963-1969 are given in Exhibit III-4.

Iron Foundry Melting Equipment

Trends in use of iron foundry melting equipment are given for the postwar period on Exhibit III-5. The cupola has shown the most dramatic change, with the number of cupolas installed in the United States declining steadily from 4,470 in 1947, to 1,930 in 1969.[3] This decline can be attributed to a combination of several factors:

1. The decline in the number of iron foundries, particularly the small foundries. For the most part the foundries which ceased to exist were operators of cupolas.
2. The replacement of cupolas by electric melting furnaces.
3. The replacement, in many foundries, of two or more small cupolas by one larger unit.

The trend toward decline in the number of cupolas is expected to continue for the foreseeable future, with the projected number being reduced to approximately 1,000 by 1980. Although the reasons given above are expected to continue to be the principal factors in this decline, other major factors are most certainly the relatively high cost of installing effective emission control equipment on cupolas and the 20-year history of rapidly increasing cost of coke which is the source of fuel as well as carbon in the cupola.

There have also been changes in the types of cupolas in operation with an increasing percentage of the new installations being hot blast units, many of them of the unlined, water-cooled type. The percentage of new installations which are of the hot blast type has increased from 24% during the period of 1947-1956, to 26% from 1957 to 1962, and to 47% from 1963 to 1968. At the same time the number of unlined, water-cooled, hot blast cupolas has been increasing from its beginnings in the mid-1950's to approximately 15% of all cupolas in service in 1969.

Trends in cupola installations have varied with the sizes of the foundries. The small foundries have invariably installed hot or cold blast, lined cupolas, but few water-cooled, unlined cupolas. Medium-sized foundries have installed both lined and unlined cupolas. The very large foundries have not installed cold blast cupolas in recent years, although some lined, hot blast cupolas have been erected. For the most part, the installations in the large foundries have been water-cooled, unlined, hot blast cupolas. These trends also have been greatly influenced by the method of operation of the foundry. Continuous tap melting for one or two shifts per day is well adapted to hot blast cupola operation, either lined or unlined. On the other hand, intermittent, batch melting is more suitably served by a cold blast cupola.

The trend toward electric melting in iron foundries has been accelerating rapidly, as shown on Exhibit III-6. Although some scattered electric melting installations existed in iron foundries prior to the mid-1950's, the great majority of the installations were made during the period of 1960-1970. The most recent census of foundries, taken in 1969, has revealed that there were some 374 electric arc furnaces installed in 176 iron foundries in the United States. However, an analysis of these installations has shown that more than half of these foundries also produce steel castings, utilizing many arc furnaces for this purpose. Since many foundries which produce both iron and steel castings use the same melting furnace for both purposes, the actual number of arc furnaces used for iron melting has been estimated to be approximately 200, located in some 100 foundries. Most of these are used for melting, but there are about 35 installations in which the arc furnaces are used for holding, duplexing and superheating of iron.

The number of arc furnace installations for iron melting has been increasing at a rate of about 15 furnaces per year. If this rate were to continue, the number of such furnaces could be expected to reach approximately 350 by 1980. However, as previously noted, the combined effects of high costs of installing emission controls on existing cupolas, and the rapidly rising costs of coke, will in all probability accelerate the rate of replacement of cupolas by electric melting furnaces. The number of arc furnaces melting iron will, therefore, be higher than the straight line projection, possibly in the range of 400 to 450 furnaces by 1980. For the most part, the electric arc furnace installations have been replacing cupolas in existing foundries, although there have been several new foundries built in recent years in which arc furnaces were installed.

In 1969, there also were 495 coreless induction furnaces installed in 191 iron foundries.[1] Approximately half of these furnaces were in foundries which also produced steel castings. Since many of these iron and steel foundries use the same furnaces for melting both metals, the actual number of these coreless induction furnaces which are used for melting iron is estimated to be approximately 300, located in some 125 foundries. Most of the coreless induction furnaces are used for melting, but about 30 of them have been used for holding, superheating and pouring of iron. The number of coreless induction furnace installations has been increasing at a rate of approximately 50 per year. As was the case for the arc furnaces, this trend will probably accelerate, resulting in an estimated 700-800 furnaces in iron foundries by 1980.

In 1969, there were reported to be 489 channel induction furnaces installed in 134 iron foundries. Although a few of these are used as melters, most of them are used for holding, duplexing, superheating and pouring of iron. These have been increasing at a rate of about 25 installations per year. If this rate continues, there will be an estimated 600 units in service by 1980.

Fuel fired melting and duplexing furnaces which are used in iron foundries generally fall into two classifications: the reverberatory-type, tilting furnaces used for melting and the stationary, reverberatory, air furnace used for duplexing of malleable iron. There has been an increase in the number of reverberatory melters in recent years, with the number in service now estimated to be approximately 100, in about 80 foundries. These are increasing at a rate of about 50 per year and may be expected to reach a total of about 250 installations by 1980, if this rate were to continue.

The reverberatory air furnace was once found in every malleable iron foundry. However, no new furnaces of this type are now being built, and the existing installations have declined to about 75, located in about 55 foundries. These can be expected to continue to decline as they are replaced by electric furnaces. By 1980, the number in service is estimated to have declined to about 40 units.

Preheaters, a type of fuel fired equipment associated with electric arc and electric induction melting furnaces, have found increasing application in the iron foundry. These units are used to both preheat scrap and to burn off combustible materials that may be embedded in or coated on the scrap, before charging into the melting furnace. The number of such units is still relatively few--no more than 50--but their use is increasing rapidly, and many of the induction melters will be equipped with preheaters in the future.

Other Equipment in Iron Foundries

Most of the iron foundries employ a form of sand or ceramic molding, utilizing a variety of molding equipment ranging from manual to fully automated and mechanized. The principal exceptions to this are those foundries producing cast iron pipe by pouring metal into rotating metal molds and those using rotating or stationary permanent molds. Although a large tonnage of iron is produced in the pipe foundries, there are relatively few such foundries by comparison with the total number of iron foundries. There are approximately 35 foundries in this category who produce about 20% of total iron foundry production.

The remaining iron foundries, with few exceptions, use sand as a molding material, and are therefore equipped with sand handling storage and conditioning facilities; mold pouring, cooling and shakeout facilities; casting cooling, cleaning and finishing facilities; and, in many cases, coremaking facilities. Because of the wide variety of types, arrangements, sizes and utilization of the equipment in these areas of the iron foundry, it is impractical to attempt to classify or tabulate facilities in all of the foundries, and this has not been done in this report.

In general, the increasing costs of labor, and the problems of recruiting and training foundry labor, have resulted in a trend toward mechanization as a means of reducing the labor content in iron casting costs. An increasing number of iron foundries are installing continuous or mechanized molding lines, sand preparation, casting cleaning, coremaking, and other facilities. This trend, which increases the facilities cost in the foundry, has also been a factor in the continuing reduction in the number of small foundries.

BASIC CHARACTERISTICS OF THE IRON FOUNDRY INDUSTRY

Compilation of Foundry Data

The large number of iron foundries in existence, reported to be 1,670 in 1969, and the general lack of detailed information on each of these foundries made impractical a complete detailed tabulation of data on every foundry.

Detailed information on approximately 170 foundries, 10% of the total number, is compiled in a data bank included in Appendix B. The nature of the data compiled includes:

1. Coded identification of foundry.
2. Type and number of furnaces.
3. Melt rate of each furnace.
4. Type of air pollution control equipment on the furnaces.
5. Collection efficiency of the air pollution control equipment.
6. Types, capacities, and number of molding, sand conditioning, coremaking, shakeout, cleaning, painting, and other emissions producing equipment.
7. Emission test data resulting from stack testing done at the foundry where available.

Because of the confidential nature of some of the information which was provided by many companies, all of the foundries are identified by a code number so that the information is presented on a basis of non-identification with any individual company.

In-Plant Foundry Visits

Part of the information for the data bank was developed from in-plant foundry visits made in 1970 by A. T. Kearney & Company, Inc. and also in 1967 as a part of a survey made jointly by the Department of Commerce and NAPCA. A total of approximately 100 foundry visits was made in these two surveys. The purpose of the visits was twofold:

1. To obtain emissions data to be used in a mathematical analysis that will identify the effect of certain design and operating variables on the type and quantity of particulate emissions.

2. To obtain firsthand reports from users of control equipment as to the effectiveness, and the operating or maintenance problems experienced with different types and manufacture of equipment.

A careful analysis of iron foundries in the United States was made to insure that the total emissions data collected reflected, to the degree possible, the effects of all identified variables in the melting systems design and operation. The steps preliminary to the selection of foundries to be visited were based on an analysis and classification of melting facilities, which is described in detail in Section VI.

THE AIR POLLUTION PROBLEM

The pollutants discharged by the iron foundry industry can be classified as:

1. Emissions from melting furnace operations.

2. Emissions from other dust-producing operations within the plant.

3. Odors and gaseous compounds from both sources.

Exhibit III-7 has been prepared to identify the principal sources of emissions in iron foundries and to indicate the types of emissions which are produced in each. A more detailed description of these processes, the emissions produced, and the methods of collection and control will be found in subsequent sections of this report.

The physical difficulties of satisfactory collection of the emissions are not easily solved and, in most cases, costs of satisfactory collection are quite high. Gases from foundry furnaces are hot and must be cooled before collection. If recirculated water is used for cooling and dust collection, corrosion problems may be introduced. Cost of fresh water is high, requiring recirculation in most cases. Most metallic oxides from melting operations are extremely small in size and require very efficient equipment for collection. In some cases, condensed metals present explosive hazards which must be considered.

Particulate emissions have been a point of focus for concentrated efforts in the control of air pollution. However, gaseous emissions and odors from the foundries have not been given much attention, and the foundry industry now has to take steps to suppress these discharges into the atmosphere. Most of the odors in foundries result from core baking and shell molding operations, but the common gaseous emissions also include vapors from melting oily metal scrap, painting operations, inoculation of metal, and from metal pouring into molds.

Air pollution control equipment has been generally considered a nonproductive expense, involving a major investment on the part of the industry without benefit of payback. The operation and the maintenance costs can be high and the equipment is generally considered to have a relatively short life. All these factors have an effect on the selection of the type of equipment to be used in a foundry installation and usually require a high level of management decisions.

These factors, which represent the nature of the air pollution problem for the iron foundry industry, indicate the need for a detailed study of the problems facing the iron foundry industry and development of technology for control of air pollution from these sources at reduced cost.

REFERENCES

1. Foundry Magazine, "Foundry Census," July, 1970, pp. 94-5.

2. U.S. Dept. of Commerce, "Iron and Steel Foundries and Steel Ingot Producers, Summary for 1968," July, 1970.

3. Foundry Magazine, "Inventory of Foundry Equipment," 1968, 1960, 1954, 1957.

IV - DESCRIPTION OF BASIC FOUNDRY PROCESSES

INTRODUCTION

The iron foundry consists of a number of distinct but strongly interconnected operations. All foundries utilize certain basic operations consisting of:

1. Raw material storage and handling.
2. Melting.
3. Pouring into molds.

Other processes present in most, but not all, foundries include:

1. Molding.
2. Sand preparation and handling.
3. Mold cooling and shakeout.
4. Casting cleaning, heat treating, and finishing.
5. Coremaking.
6. Pattern making.

A simplified, schematic flow diagram encompassing most of these processes is presented in Exhibit IV-1.

Each operation contains equipment and processes capable of producing emissions which may include gas, fume, smoke, vapor and particulate matter. The latter can range from metal dust from grinding operations, that is relatively easy and inexpensive to collect, to extremely fine ferrous and nonferrous oxides from melting furnaces that are very expensive and difficult to collect. The sources of these emissions are schematically indicated in Exhibit IV-1, and the operations are described in the following paragraphs of this report.

PROCESS FLOW FOR GRAY, DUCTILE AND MALLEABLE IRON

The basic process flows for gray, ductile, and malleable iron are shown in Exhibit IV-2. In general the flow is similar for each of the three types of iron, except for the variations shown in the exhibit.

The most common flow pattern in the iron foundry industry is the one for gray iron production. The process flow for ductile iron differs from gray iron principally by the addition of two operations--the magnesium treatment to nodularize the graphite in the iron and the press straightening which is sometimes required.

Malleable iron process flow is also similar to gray iron flow with the exception of an annealing operation required to convert the as cast "white" iron into malleable iron, and the press straightening sometimes required to correct the warping that results from the annealing process. In other regards the process flow for malleable iron is the same.

Specifications for various classes of gray, ductile, and malleable iron are tabulated in Exhibits IV-3, IV-4, and IV-5.

PROCESS FLOW AND DESCRIPTIONS OF BASIC FOUNDRY OPERATIONS

Detailed process flow diagrams for each of the basic iron foundry production operations are depicted in referenced exhibits, except for cupola melting. Heat and material balances for cupolas are included in Appendix C with a description of the mathematical model developed for calculating the heat and material balances. Brief descriptions of the operations are given on the following pages. More detailed information on the basic operations can be obtained from referenced sources.

Raw Material Storage and Furnace Charge Preparation

(a) Raw Material Receiving and Storage

The raw materials used for iron production fall into the following classifications:

1. Metallics:
   - (a) Pig iron.
   - (b) Iron and steel scrap.
   - (c) Turnings and borings (loose or briquettes).
   - (d) Ferroalloys.
   - (e) Foundry returns.
   - (f) Alloys such as nickel, copper, tin and magnesium.
2. Fluxes:
   - (a) Carbonate type (limestone, dolomite, soda ash).
   - (b) Fluoride type (fluorspar).
   - (c) Carbide type (calcium carbide).

3. Fuels-Coke (for cupolas).
4. Refractories.

These materials, except for foundry returns, are received by railcar or truck, and are unloaded and stored in the foundry scrapyard. Although open scrapyards are still common, the use of covered storage areas is becoming more widespread to reduce the rusting of ferrous scrap and the weathering and degradation of coke and limestone. Covered storage is also desirable for induction melting scrap which must be dry when charged into the furnace. Scrap metals, pig iron, and foundry returns are usually stored in piles which may be unconfined, but are often separated by walls to form open bins. Coke and stone may also be stored in piles, but are commonly stored in confined bins to facilitate charge makeup.

There are no industry standards for foundry coke. Size classifications up to 6" x 8" are available depending on the requirements of each foundry. The range of proximate analysis values for foundry coke are as follows:

Volatiles	0.7% - 1.25%
Ash	4% - 12%
Fixed Carbon	86% - 95%
Sulfur	0.5% - 1.0%

Specifications for ferrous scrap metals are tabulated in Exhibit IV-6. Pig iron and commonly used ferroalloy specifications are shown in Exhibit IV-7.

(b) Scrap Preparation

For the most part, scrap materials, including foundry returns, are used in the as-received form. Many scrap dealers prepare scrap to foundry specifications, thus eliminating any need for additional preparation by the foundry. Where scrap preparation is required, the operations may involve any combination of the following:

1. Cutting to size by flame torch, shear, breaking, or fragmentizing.
2. Cleaning by degreasing, by steam or by shot-blasting.
3. Burning of surface coatings or oils.
4. Drying or preheating.

With the exception of the cutting operations, scrap preparation is not widely performed for cupola melting, or for top charged electric arc furnaces. However, for electric induction furnaces, a greater degree of preparation is necessary to obtain dry, clean scrap of the proper size.

(c) Furnace Charge Preparation

The methods of makeup and handling of melting furnace charges vary widely from completely manual systems where all materials are hand shoveled or carried, to highly mechanized systems where one man can control the handling, weighing, and loading of all raw materials.

Charges are normally loaded directly into the furnace charging bucket, skip, or similar container. The prescribed combination of metallics, flux, and coke (for cupolas) is weighed either before loading or while loading.

Where preheating or drying operations are performed, they are commonly done directly in the charge containers. This can be accomplished by heating from above with a flame or radiant burner, or by use of a double-walled bucket in which combustion is accomplished within the wall cavity. Other methods include the use of rotary dryers, heated conveyors, and preheat furnaces. Process flow for scrap preparation and change makeup is shown in Exhibit IV-8.

Iron Melting

The process flow in the foundry melting department i depicted in Exhibit IV-9. Four types of melting furnaces representing over 98% of the installed melting systems are considered in the flow diagram. A 1968 study, covering about 75% of all foundries, showed the following distribution of melting furnaces in the iron foundry industry.[1]

Iron Foundry Melting Furnaces - 1968

Furnace Type	Number Installed	Percent of Total
Cupola	1,232	89.5%
Electric Induction	73	5.3%
Electric Arc	42	3.1%
Other Types	29	2.1%
Total	1,376	100.0%

The furnace census does not show the number of reverberatory furnaces in use, but it would be expected that they constitute the majority of the 2.1% indicated as "Other Types." Despite the low incidence of use, this method of melting is of interest because of its reported low emission of particulate matter, and its increasing use in small foundries.

The process flow diagram shows the metallic and flux materials charged into each type of melting furnace. The reverberatory furnace is heated by coal, natural gas or oil, while the induction and arc furnaces obtain their heat from an electric induction coil or an electric arc. In the cupola, coke is a portion of the furnace charge and the heat required to melt the iron is derived from the combustion of the coke in contact with the metallic and fluxing charge materials.

The molten metal from the furnaces is tapped directly into a ladle for direct mold pouring, into a transfer ladle for conveying to the molding area, or into a heated or unheated holding device.

From a cupola, the hot metal can be transferred to a forehearth, or an electric induction or arc furnace for holding, or into a reverberatory duplexing furnace if the final product is to be malleable iron. With the exception of the forehearth, a similar selection of holding or duplexing furnaces is available for electric or fuel fired melting furnaces. As the metal is available and required, it is removed from the holding or duplexing furnaces for transfer to the molding area.

(a) Cupola Furnaces

The cupola is a vertical furnace with a normally circular cross section which is charged alternately with metal to be melted, fuel in the form of coke, and a fluxing material, to produce molten iron of a specified analysis and temperature. Many fundamental cupola designs have evolved through the years, two of which are widely in use at this time--the conventional refractory lined cupola and the more recent development, the unlined, water-cooled cupola.

1. Conventional Lined Cupola. For all cupola designs, the shell is made of rolled steel plate. In the conventional design, an inside lining of refractory material is provided to protect the shell from the operating temperature. The cupola bottom consists of two semicircular, hinged steel doors, supported in the closed position by props during operation, but able to be opened at the end of a melting cycle to dump the remaining charge materials. To prepare for melting, a sand bed 6 to 10 inches deep is rammed in place on the closed doors to seal the bottom of the cupola.

Combustion air is blown into the wind box, an annular duct surrounding the shell near the lower end, from which it is piped to tuyeres or nozzles projecting through the shell above the top of the rammed sand. The tap hole through which the molten iron flows to the spout is located at the level of the rammed sand bed. For nearly all continuous tap operations, the slag also is discharged through the tap hole and separated from the iron by a skimmer in the runner. For intermittent tapping, molten iron collects in the well with the slag floating on its surface, and a slag hole is located at the level representing the height of the maximum amount of iron desired to collect in the well. An opening is provided in the cupola shell 15-25 feet above the bottom plate for charging the cupola. The charging door opening varies in size according to the intended method of charging and the diameter of the cupola. The upper stack is extended sufficiently to pass through the building roof and provide the required natural draft. On open top cupolas, a spark arrestor is fitted to the top of the stack to reduce the hazard of fire.

The shell of a conventional lined cupola is protected with a refractory lining. The lining is usually built up using high-duty fireclay shapes for acid melting and magnesite shapes for basic melting. An illustration of a typical conventional lined cupola is depicted in Exhibit IV-16.

2. Water-Cooled Cupola. The unlined, water-cooled cupola utilizes a steady flow of cooling water on the outside of the unlined shell generally from below the charging door to the tuyeres, and an inside lining of carbon blocks below the tuyeres to the sand bed, to protect the shell from the interior temperature. Conventional lining is used at the charging door level and in the upper stack. In other regards, the water-cooled cupola is essentially the same as the lined cupola. Exhibit IV-17 shows two types of water-cooled cupolas.

3. Blast Air. Combustion air is supplied to the cupola in appropriate amounts depending upon the desired melting rate and the size of the coke charge, at a pressure related to

the volume and height of the burden. The air is piped from the blower, which can be a centrifugal or positive displacement type, to the wind box, and thence to the tuyeres, spaced equally around the cupola shell. In a normal design, a single row of tuyeres is used. In the balanced blast cupola, the blast air is divided between three rows of tuyeres with the provision for adjusting the flow of air through each tuyere. Varying the flow in a regular sequence prevents bridging of the charge at the tuyere and results in greater combustion efficiency and higher melting rate.

The temperature of the blast air has a strong effect on coke requirements, melting rate, and cost of melting. The heat supplied by warm or hot blast decreases the BTU's required from the coke and therefore permits the coke charge to be decreased, or the melting rate to be increased. Where the cost favors natural gas or oil over coke, the heating of the blast air with these fuels can lower the cost of melting. Early efforts at heating the blast air resulted in temperatures of 300°-400° F. Later, temperatures of 1000°-1200° F were used successfully and, recently, a successful installation with 1800° F blast air has been reported.

Most air preheater installations in the United States are externally fired, although many attempts have been made to successfully recover the latent and sensible heat of the cupola with varying results. Some of the problems in developing successful units were maintaining the heat exchanger, keeping the heat transfer surfaces clean while passing dirty gas through them, and designing a system low enough in cost to make the installation economically feasible.

4. Fuel Injection. Numerous attempts have been made to inject coal, oil, or gas into cupolas to replace a portion of the coke required to melt the iron. Successful results have been reported for natural gas injection resulting in lower melting costs. No tests using coal or oil have been reported in recent years.[2]

5. Oxygen Enrichment. A number of foundries are injecting oxygen into the cupola with resulting increased melting rates. One potential advantage of this technique is that the stack gas volume is decreased, since the oxygen used for combustion does not carry with it the inert volume of nitrogen found in air.

6. Closed Top Cupolas. In either recuperative hot blast cupolas, or where there is a requirement that cupola stack gases be cleaned before releasing them into the atmosphere, the normal practice is to close the top of the cupola and draw the gases off either just below the cap, or below the charging door. If collection is above the charging door and the door is always open, air is infiltrated through the opening substantially increasing the volume to be handled, and therefore increasing the cost of the control system. If the door is normally closed, the infiltrated air volume will be lower but oxygen present in the gases may be insufficient to burn the CO to CO_2. A compromise is sometimes reached where doors are provided that permit infiltration of enough air to aid in complete combustion of the CO.

7. Afterburners. The cupola gas rising from the top of the burden is rich in carbon monoxide. When mixed with air infiltrated through the charge door opening, this gas becomes a combustible mixture and it is desirable that it be ignited at this point. Combustion normally occurs here because of the gas temperature, but the flame is sometimes extinguished when the charge is discharged from the charging bucket. To assure reignition, a gas torch, or afterburner, is often installed in the cupola just above or below the charging door. The afterburner performs the additional function of incinerating oil vapors, coke particles and other combustibles.

8. Cupola Operation. At the beginning of the melting cycle, a coke bed is placed on the rammed sand bottom and ignited, preferably with a gas torch or electric igniter. Additional coke is added to a height of four or five feet above the tuyeres after which regular layered charges of metal, limestone and coke are placed on the coke bed up to the normal operating height. Typical cupola charges for gray, ductile, and malleable iron are included in Appendix C. The air blast is turned on and the melting process begins. As the coke is consumed and the metal charge is melted, the furnace contents move downward in the cupola and are replaced by additional charges entering the cupola through the charging door.

As the metallic charge moves downward, it is preheated by the hot gases resulting from combustion. These gases consist of carbon monoxide, carbon dioxide, nitrogen, hydrogen, and sulfur dioxide, the latter principally from the sulfur contained in the coke. As the metal enters the melting zone, the atmosphere is of a highly reducing nature with no free oxygen. The molten iron, trickling down over the incandescent coke and increasing in temperature, reaches the combustion zone where the atmosphere becomes oxidizing in nature, due to the presence of oxygen from the blast air. In this part of the cupola, the iron reaches the desired tapping temperature.

Blast air entering the cupola through the tuyeres contains 21% oxygen which combines quickly with the carbon in the coke as follows:

$$C + O_2 \rightarrow CO_2 + 175{,}900 \text{ BTU/pound mole}$$

The oxidizing zone in which this reaction occurs is designated the combustion zone. It is the zone of highest temperature and extends from the tuyeres to a level where the following reaction occurs:

$$C + CO_2 \rightarrow 2\ CO - 69{,}700 \text{ BTU/pound mole}$$

The reduction of CO_2 to CO starts before all oxygen in the blast air is consumed. The maximum CO_2 concentration is believed to be approximately 14%-18% at the boundary of the oxidation and reduction zones at a maximum temperature of $2{,}800^\circ$ -3400° F. Both reactions noted are reversible and proceed in both directions depending upon conditions at different levels. The reactions almost cease in the preheat zone as energy is used to preheat the charge materials and the gas temperature is lowered to the reaction temperature below which further reduction of carbon dioxide to carbon monoxide will not occur.[3] A pictorial description of a cupola reaction area is shown in Exhibit IV-18.

9. Cupola Furnace Operations Model. Approximately 300 iron foundry melting systems in the United States are currently equipped with some type of air pollution control equipment, ranging from wet caps to fabric filters, wet scrubbers, and electrostatic precipitators. A detailed investigation of about 170 of the cupola systems included in this total showed that they could be characterized by only 32 classifications, each one representing a specific combination of cupola design factors.

In Appendix C, the heat and material balances for each class are tabulated and the classifications are depicted pictorially. The heat and material balances were derived by the use of a computerized mathematical model designed to calculate these balances for a given set of cupola operating conditions. Input data were obtained from the records of about 50 foundries visited in 1970 and from test data in the files of various city and state air pollution control boards. Details of the computer program developed to make the calculations are included in Appendix C.

In addition to the description of the heat and material balance model, Appendix C includes the following data:

- Specific Inputs Required for the Model. Input data required for the calculations are tabulated.
- Chemical Reactions Considered in the Model. Chemical reactions considered to have a qualitative and quantitative effect on emissions produced in a cupola used to produce iron are listed.
- Material and Heat Balance Relationships Considered in the Model. Theoretical and empirical material balance relationships upon which the model is based are listed. Similar relationships for the heat balance calculations are shown.

- Sample Outputs for Material and Heat Balances. Sample outputs for material and heat balances are included in the appendix. The appendix indicates the format of the computer output. Material balance inputs are acceptable either in pounds of charge materials or a percentage of total charge weight. The model calculates the balance and prints the outputs in pounds per ton of molten iron.

  Heat balance outputs are printed out in thousands of BTU's per hour. The program also computes the volume of the top gases, and a theoretical analysis of the stack gases including air infiltrated through the charging door if the input indicates that the cupola is operated with the door open.

- Composition of Materials. To simplify the computation, the model makes use of standardized material compositions for metallic charge materials and products, fluxes, coke ash, and cupola refractory linings.

(b) Electric Arc Furnace

1. Description. The direct arc electric furnace consists of a refractory lined, cup shaped, steel shell with a refractory lined roof through which three graphite or carbon electrodes are inserted. The shell is arranged for tilting to discharge the molten metal. Charging of the metal is accomplished by chuting through a door opening in the side of the shell, for fixed roof furnaces, or by raising the roof and swinging it aside to permit the use of a bottom dump charge bucket for removable roof furnaces. Foundry size furnaces generally range in diameter from about 3'0" to 12'9" with holding capacities of 500 pounds to 25 tons, and melting rates from 250

pounds to 12 tons per hour. Larger furnaces have recently been installed for melting iron, one large production foundry having recently put into service a 65-ton capacity arc furnace with a melting rate of about 22 tons per hour. For iron melting with light scrap, the inside depth of the furnace is approximately 75% of the inside diameter. Furnace shells are of welded construction, often with a water-cooled section at the top edge. The furnace roof is provided with a circumferential water-cooled ring, and water-cooled electrode glands. Tilting mechanisms are mechanical or hydraulic, the latter being of later and more satisfactory design from the standpoint of precise controllability. The furnace is provided with a tapping spout and a working door, with a second door for large furnaces.

The electrodes, supported by water-cooled holders, are provided with a hydraulically or mechanically operated raising and lowering mechanism to maintain the arc, especially during meltdown. The electrodes and roof on a top charge furnace are supported independently from the shell and are arranged to permit raising to clear the shell and rotating to one side for charging.

A transformer vault adjacent to the furnace is required to house the current and potential transformers, circuit breakers, high and low voltage wiring, low voltage bus bars, secondary furnace cable connections, and instrument panel. A control panel and operator's console are required near the furnace. Multi-voltage, tap charger transformers are used to make voltage changes as necessary during the melting cycle.

The furnace bottom refractory lining can be either acid with a rammed ganister mix over silica brick, or basic with a rammed magnesite mix over silica brick, although acid lined furnaces are generally used for melting iron. Sidewall lining is generally a high alumina fire brick. The bottom lining is subjected to abrasion and crushing during charging, but commonly remains serviceable for months. The sidewall is subjected to both abrasion and the effect of the molten iron and slag and requires patching between heats. The roof lining made of high alumina brick is subjected to high temperature and effects of metal and slag splatter from the arc. A typical electric arc furnace with supporting equipment is illustrated in Exhibit IV-19.

2. Electric Arc Melting. For top charge furnaces, the charge materials are usually weighed into bottom dump buckets. When charge preheating is used, the heating may be accomplished in a specially designed, refractory lined bucket, a double walled bucket, or the charge transferred to a preheating chamber, and then moved to the furnace. A cost-saving potential exists in preheating the charge in the charge bucket, by substituting a lower cost fuel to raise the charge temperature to 1200°-1400° F.

In charging a side charge furnace, the metal charge is often weighed into a trough-shaped bucket, which is transferred to the furnace and tilted to permit the charge materials to slide into the furnace door opening. When using the arc furnace as a hot metal holder, the hot metal from the primary melter can be transferred to the arc furnace by ladle, or by refractory lined launder, and discharged into the charging opening.

Exhibit IV-10 shows the composition of a typical charge, heat, and material balance. The carbon required in addition to the carbon content of the scrap is derived from the petroleum coke added to the charge and from the electrode material consumed during the melting cycle. Since there is no coke ash requiring fluxing as in the cupola, only small quantities of flux materials are needed. Chemical reactions occurring within the furnace also are few compared to the cupola, since there is little combustion. The fume generated, particularly at the start of meltdown, is the result of locally intense heat caused by arcing of the electrodes before a molten pool of metal is formed. Oxides of iron and other elements contained in the charge materials are formed at this time, by vaporizing some of the charge.[4]

3. Indirect Arc Furnace. The indirect arc or rocking arc furnace is more commonly used for nonferrous and high alloy melting than for iron melting, but is found in many smaller iron foundries. It consists of a refractory lined horizontal drum which rotates about its longitudinal axis for charging and tapping. One electrode is located in each end, with the resultant arc being struck above the charge, resulting in melting from an indirect arc as contrasted with the direct arc

in the more commonly used arc furnaces. These furnaces are built only in small sizes, from a few hundred pounds to four-ton capacities.

(c) Induction Furnaces

1. Description. The induction furnace is a cup- or drum-shaped vessel that converts electrical energy into heat to melt the charge. Unlike the electric arc furnace, no electrodes are required. The induction furnace converts electrical energy into heat by utilizing the transformer principle in which a magnetic field is set up when the primary coil of the transformer is energized. The magnetic field at a high flux density induces eddy currents in the charge which are converted to heat by the electrical resistance of the charge itself.

The heat is developed mainly in the outer rim of the metal in the charge, but is carried to the center by conduction until the metal is molten. The electrical energy is converted into heat by induction in two ways. In the channel induction furnace, the metal charge surrounds the transformer core, thereby forming a loop or channel. In the coreless induction furnace, the metal heated is both the core and secondary coil. Furnace coils are water-cooled to prevent heat damage.

The amount of heat developed in the furnace is a function of the electrical current frequency and the intensity of the magnetic field. Theoretically, there is no limit to the temperature attainable; however, a practical limit exists due to material limitations such as refractory lining of the furnace.

At present, commercial linings are available for temperatures somewhat over 3000^{o} F.

2. Operating Characteristics. The induction furnace lends itself to either semicontinuous or batch-type operations and can be used as a melting furnace or for holding or duplexing operations. Generally, the coreless furnace is better adapted to melting and superheating, whereas the channel furnace is better suited to superheating, holding, and duplexing, although it is also sometimes used for melting. Exhibits IV-20 and IV-21 illustrate channel and coreless induction furnaces.

Coreless furnaces are available in high, medium and low frequency types. Installations for iron melting and holding are generally limited to the low or line frequency of 60 cycles, and medium frequencies of 180 cycles.

The coreless design permits melting of a cold charge for each cycle, allowing frequent analysis change. The energy is constantly induced into the entire charge so that temperature differentials within the melt are minimal. This is not the case in a channel induction furnace where energy is induced only in the molten metal actually in the channel. Despite the ability of the coreless furnace to melt cold charges, most production foundries maintain a heel of molten metal in the furnace to increase efficiency and lower thermal shock to the refractory lining. The scrap charge must be dry for this method of operation to prevent explosions that would result from addition of moisture to a molten metallic bath.

3. Charging. Melting losses are low and the recovery of alloying additions is high in induction melting of gray iron. The charge may consist of a single lump of metal, a number of small pieces of selected scrap, or even turnings. Charges are usually made up of steel scrap, cast iron scrap, foundry returns, and ferrosilicon and carbon in suitable quantities to adjust composition. Pig iron is seldom used. Turnings and borings are readily melted in a coreless furnace, although care must be taken to avoid oxidation before melting has occurred.

When available, turnings or borings can comprise up to 20% of the charge in a coreless furnace. Carbon adjustment is accomplished by the addition of pelletized coke. Preheating of the charge is considered beneficial from the standpoint of removing moisture and oil as well as reducing melting costs and shortening the melt cycle.

Charge materials are commonly weighed into a bottom dump charging bucket, although small furnaces can be charged manually. In some cases, the charge is collected in pans placed on the working platform and is dropped into the furnace either by tipping the pan or by raking the pieces out of the pan and into the furnace. Charging into the furnace is from the top. Additions of carbon and ferrosilicon are made directly into the furnace.[4]

4. Melting. The induction furnace is basically a batch melter. Continuous melting is possible with a recently developed coreless furnace and approximated in the conventional design by partial tapping of a melt followed by a makeup charge of cold scrap.[5]

A strong stirring action from electromagnetic forces is exerted on the molten bath in a coreless furnace. The stirring action helps to obtain a homogeneous melt when ladle additions for carburizing and analysis correction are made. The mixing action is less in a channel-type furnace.

The analysis of the iron from induction melting is highly reproducible due to the general lack of unpredictable or undesirable reactions in the furnace. Induction melting does not alter the chemical composition of the molten metal from the original charge. However, since it is not a refining process, care must be exercised in the makeup of the charge. The process flow for coreless induction melting is shown in Exhibit IV-11.

Induction furnaces are more efficient superheaters than cupolas or arc furnaces.[6] For this reason, high tapping temperatures are more practical with coreless and channel induction furnaces, and these units are often used for superheating, and where hot metal must be held for an extended period of time, induction furnaces have been used for feeding automated casting lines with the metal being tapped as required, and often held at pouring temperature when molding is delayed for some reason.

5. Furnace Sizes. Coreless induction furnaces are found in an extremely wide range of sizes, from under 100 pounds capacity, to recently designed installations of 70 tons and larger. Similarly, channel induction furnaces vary widely in size, from a few hundred pounds to 260 tons in holding capacity.

Power inputs range from under 100 kw, to 17,000 kw for coreless furnaces, and up to 4,000 kw for channel furnaces.

(d) Reverberatory Furnace

The reverberatory type of fuel fired furnace is found in two types of applications in the iron foundry. The large, stationary reverberatory or air furnace is associated with malleable iron foundries, where it has long been used as a duplexing unit in conjunction with a cupola. These furnaces are generally powdered coal fired, although oil and gas are also used. Most are not melters, but are used to receive molten iron from the cupola, and to refine and superheat it for pouring. These furnaces are long, rectangular units with arched or suspended roofs, generally fired from one end, and with waste gases exhausting into a stack from the opposite end. Temperatures of 2900° F and higher are reached in these furnaces. Holding capacities range up to 40 tons.[4, 7] A typical furnace of this type is shown in Exhibit IV-22.

The second type of reverberatory fuel fired furnace is used for melting. It is generally small in size, up to two tons capacity, and tilts for pouring. Furnaces of this type are found in small foundries, where economical installations and low emission melting are desired.

Inoculation

Inoculation is a process applied either in the production of ductile iron, where it is known as magnesium treatment, or to improve the mechanical properties of castings.

(a) Ductile Iron Production

In the production of ductile iron, agglomeration of spheroidal graphite is accomplished by treatment of the base iron while in the ladle. A number of inoculating agents including magnesium, calcium, cerium, and yttrium are suitable, although magnesium is most widely used. The relative economics and availability of these materials have resulted in the common use of magnesium for this purpose. Many techniques have been developed to place the inoculant in the molten iron using magnesium in the pure form, in a variety of alloys, and impregnated in coke. No single form has been universally accepted, although nickel-magnesium, copper-magnesium, magnesium-silicon-iron, nickel-silicon-magnesium alloys, and magnesium impregnated coke are frequently employed. The speed and violence of the reaction is due in part to the concentration of magnesium in the alloy or coke. Some of the treatment techniques used to produce ductile iron are shown in Exhibit IV-23.[8]

(b) Improvement of Mechanical Properties

The inoculation process is applied to molten gray iron to obtain a desired shape, size, and distribution of graphite in the finished casting. The effect of an inoculant depends on the type and amount used, the temperature and condition of the molten iron at the time of addition, and the amount of time that elapses between inoculation and pouring.

Inoculants contain various amounts of carbon, silicon, chromium, manganese, calcium, titanium and other elements. Inoculant effects include decreasing chill depth and increasing tensile strength.

An inoculant can be introduced to the molten metal in the cupola spout, forehearth, transfer ladle, pouring ladle or mold.[4]

Duplexing

Where large tonnages are needed, or where a continuous supply of molten iron is required to pour conveyorized molding lines, duplexing melting systems are often employed. In duplexing, iron is melted in one furnace, usually a cupola, and refining and temperature control are achieved in a second furnace. The melter is continuously tapped into the second furnace (an air or electric unit) which is then tapped intermittently into transfer ladles for pouring into molds. The second furnace accomplishes carbon adjustment and serves to decrease analysis variations of metal coming from the cupola. Duplexing is also used in the production of malleable iron.[7]

Molding, Pouring, Cooling and Shakeout

Many molding materials and types of equipment have been developed for the production of iron castings. Techniques found in current practice include green sand, dry sand, shell, hot box, the full mold process, permanent metal molds, and the Rheinstahl process where stationary molds are used with both lined and unlined rotating molds for centrifugal casting.

Exhibit IV-12 illustrates the process flow for molding, pouring, and shakeout.

(a) Green Sand Molding

Of all the types of molding in use today, by far the greatest tonnage of castings is produced from green sand molds. They are commonly made of silica sand, clay, water, and organic binders such as cereal binders mulled together to form a moist mixture suitable for use with manual or automated molding machines and sand slingers. Green sand molds are the least costly of all molds to produce.

A typical molding operation is done with the aid of jolt-squeeze draw machines. The complete operation is often performed in two separate machines. A jolt-squeeze-rollover-draw machine for drag molding and a jolt-squeeze-draw machine for cope molding are used. Molding machines capable of molding cope and drag simultaneously in one molding cycle are also utilized.

Mold production by a single machine can also be performed by match plate molding machines or on an automatic molding line. In automatic molding lines, the entire green sand molding sequence is automatic with preset time cycles.

Very large green sand molds, beyond the capacity of conventional molding machines, are often made with a sand slinger. This machine propels small amounts of sand into the mold with enough force to eliminate the need for machine jolting.

Green sand molds are occasionally skin dried or air dried to produce better finish. Drying removes moisture or other gas forming materials in the sand at the mold-metal interface. Molds which have to be skin dried are either faced with sand mixtures containing thermosetting additives or they are washed or sprayed with a refractory mold coating to prevent metal penetration.

(b) Centrifugal Casting

Cast iron pressure and soil pipe is normally made in permanent molds. The molds are rotated rapidly about their longitudinal, horizontal axis during the pouring and cooling cycles producing a dense, high quality casting. A dry sand or shell sand core is inserted in the mold to form the bell end of the pipe only. Cast iron pipe tonnage represents approximately 20% of the total iron casting production. Centrifugal casting is also used for production of other types of castings, generally of a symmetrical design.

(c) Dry Sand Molding

Dry sand molding is usually applied to thick section castings of fairly large size or weight such as machine beds, cylinders, and heavy gears. The sand mixes for this type of work contain certain additives such as pitch, sodium silicate, gilsonite, cereal, molasses, dextrine, gluten, and resins. These additives set at the drying temperature employed, or by chemical reaction with curing agents, and produce a high dry strength and rigid mold walls.

In general, dry sand molding involves assembling the mold through the use of a number of parts of the mold which have been prepared using a dry sand mix. These smaller mold parts are prepared in the same type of equipment as used in green sand molding where the dry sand mix is poured into the permanent metal mold and compressed to form a section of the larger mold. These sand molds are then baked in an oven where drying or baking takes place at temperatures of 300°-600° F. After cooling, the baked dry sand molds are assembled to form the complete mold for the casting.

(d) Shell and Hot Box Molding

The shell molding process for making castings is used where dimensional accuracy and surface finish of the part is important. This molding technique has found wide acceptance in the foundry industry. The sand used consists of a mixture of dry sand grains and synthetic resin binder. The resin must be a thermosetting type since the strength developed by the mold depends entirely on the strength of the binder after the mold has been heated.

The equipment used for molding consists of a metal box which houses the pattern plate and is heated to a temperature of 350° to 700° F. The sand mix is then blown into this hot box where the resin partially thermosets and builds up a coherent sand shell next to pattern. A mold release agent or a parting agent is necessary so that the ejector pins can push the shell off the patterns. The cleaned shell halves, thus produced, may be assembled and poured. Shell molds may require cores and the core setting is done prior to the assembly of shell halves.[9]

(e) Full Mold Process

The full mold process is a patented recent development which involves the use of materials such as polyurethane or polystyrene foam to fabricate patterns where small runs of complicated designed castings are to be made. In this process, the pattern is either machined from a single block, or indivual pattern pieces are cut and then glued or fastened together. These patterns, with attached gating system, are then buried in sand. Various cold setting sand mixes are commonly used. Some work has been done with unbonded sand. Little success has been achieved with green sand since the ramming pressures deform the patterns. Metal is poured into the mold, vaporizing the pattern and replacing it with metal. An advantage of full molding is that pattern design does not have to consider pattern removal from the sand since each pattern is destroyed in the pouring process.

(f) Rheinstahl Process

Another recent development, the Rheinstahl process, consists of using cement as a binder and a fluidizing agent that promotes a high density casting mix that results in a cement-bonded, fluid molding sand. The fluidizer is added to the sand as it is being prepared in a muller or paddle-type mixer. The reported advantage of the Rheinstahl process is that ramming time is practically eliminated since pouring can occur almost immediately after sand is placed in the mold.[10]

(g) Pouring and Cooling

In a high volume production foundry, finished molds are set out on continuous car-type or indexing mold conveyors, or on pallet conveyor lines. In smaller production and jobbing foundries, completed molds are set out on the foundry floor or on gravity roller conveyors.

In mechanized production foundries the molds are usually poured within minutes of completion. Most small foundries, however, may pour only a few hours a day, or only two or three days a week. In these cases the molds are usually set out on the foundry floor until hot metal is available. A pouring station in a mechanized foundry is illustrated in Exhibit IV-24.

(h) Shakeout

In many foundries the casting is separated from the molding sand manually. Even in partially mechanized foundries where completed molds are set out on gravity roller conveyors for pouring and cooling, the molds are dumped manually and the castings picked or hooked out of the sand and placed in a totebox for further cooling and moving to the cleaning room.

Larger and more mechanized foundries tend to use a heavy-duty vibrating screen for shaking-out. The sand flows through the screen openings to the return, or shakeout sand system, for transfer to the sand conditioning system. The castings are removed from the shakeout grid manually, by a hoist, or by action of the vibrating screen, for cooling and sorting. Exhibit IV-25 shows a shakeout work station.

Sand Conditioning

Sand is a basic foundry material used in substantial volume by almost all foundries as a molding medium. The complete sand system consists of receiving and storage facilities, molding sand preparation, and the handling equipment required to transfer the sand to its points of use, preparation, and discard. In addition, some high production foundries using very large amounts of sand have reclamation systems for returning used sand to its original condition, or as near to it as is practical and economical.

The sand conditioning process flow diagram is given in Exhibit IV-14.

(a) Receiving and Storage

Raw materials requiring handling and storage after receiving include the silica sand and various additives such as clay, carbonaceous materials, synthetic resins, and cereal binders. In addition, some foundries doing shell molding purchase premixed shell sand. Silica sand is received by car or truck, unloaded and conveyed manually, mechanically, or pneumatically, and stored in covered areas or in enclosed bins or silos. Shell premix may be shipped in bulk or in multiwall bags depending on usage. Solid additives are received in bags or fiber drums, and liquid additives in metal barrels.

(b) Sand Preparation

In past times, naturally bonded molding sand was universally used for green sand molding. Preparation of the sand for reuse consisted of adding water and some new sand to replace the amount sticking to, or embedded in, the surface of the castings. This sand has been almost completely replaced by clean silica sand to which is added water and the various binders required to produce the desired molding characteristics.

Sand preparation in the majority of today's foundries is accomplished on the foundry floor by adding moisture, binders, and new sand to the used sand. A number of types of mobile and portable equipment are used to cut, screen, mix, and aerate the sand to prepare it for reuse.

Mechanized foundries are generally equipped with fixed sand preparation equipment to which the shakeout and spill sand is transported by conveyors and elevators. After preparation, including magnetic separation of tramp iron, screening, addition of binders and moisture, mulling, and possibly aeration, the prepared sand is conveyed to the molders. Exhibit IV-26 illustrates a typical sand mulling unit.

High production foundries normally reuse the molding sand a number of times each shift. If the sand is not effectively cooled after each use, the temperature builds up to the point where evaporative cooling of the prepared sand occurs. A significant amount of moisture added in the muller can be lost before the sand can be formed into a mold resulting in a change in the characteristics of the sand. This condition plus the heat remaining gives rise to casting defects. Conventional cooling is accomplished in the muller by directing a flow of cool air through the mixer. A new concept, absorption cooling, has recently been patented and is in use in several foundries with reported success. This process is described in Section IX.[11]

(c) Sand Reclamation

Three basic types of sand reclamation units are available--dry, wet, and thermal. In the dry system the sand is first screened and crushed to reduce the lumps and is then discharged into a dry scrubber where the grains are subjected to the blowing action of low pressure, high velocity air. The resulting impaction and scrubbing action between individual grains cleans the sand. For wet reclamation the sand, after screening and crushing, is slurried with water and pumped into a wet scrubber equipped with a rapidly revolving propeller. The sand is agitated violently, causing multiple collisions of the grains. The slurry is next pumped into a classifier where the fines are removed. Finally, after draining, the sand is dried and cooled. The thermal reclaimer consists of a multiple hearth furnace into which the screened and crushed sand is fed. The sand is heated to about 1300° F and plowed from shelf to shelf within the gas fired chamber. Cooling and screening to remove the sand fines complete the reclamation.[9, 13]

Cleaning, Heat Treating and Finishing

Cleaning and finishing of castings are the final operations performed in the foundry. Cleaning of castings generally refers to the operations involved in the removal of sand and scale; sprues, gates, and risers; and fins, wires, chaplets or other metal not a part of the casting. The castings, after they have been separated from sand at the shakeout screen, are cooled in boxes or on a conveyor which moves them to the cleaning and finishing area. For gray iron castings, the gating system may be broken off by impact in the shakeout, or they may be removed on the casting delivery conveyor. Heads and gates on ductile iron castings may require burning or sledging.

These operations are shown on Exhibit IV-13.

(a) Cooling and Sorting

Following shakeout and sprue removal, castings are cooled before being sent to the cleaning and finishing area. Cooling can be accomplished in a variety of ways, depending on the size and shape of the castings, the rate at which castings are produced, and the degree of mechanization in the foundry. Several types of conveyors--pallet, flat chain, belt, and overhead chain--are used in high production shops, while other shops cool in boxes or simply by piling the castings on the floor. Sorting is generally done after a sufficient amount of cooling and involves separating the different products into handling containers.

(b) Castings Cleaning

The removal of sprues, gates and risers is usually the first operation in the cleaning room. This is done by impact, shearing, abrasive cutoff, band or friction sawing, or torch cutting depending upon the size of the casting and the type of iron. Abrasive cutoff wheels can be used for removing gates and risers on castings made of hard- or difficult-to-saw alloys. Gates and risers on large ductile castings are most conveniently removed by gas cutting. Band or friction sawing may be used where it is desirable to follow the contour of the casting.

Surface cleaning operations ordinarily follow removal of the gating system for all foundry castings except malleable iron castings which are heat treated before surface cleaning operations. Abrasive operations such as shotblasting, sand blasting, and tumbling are normally used. Wire brushing, buffing, pickling, and polishing operations may also be performed in some cases.

Shotblasting the casting surface is a rapid means of removing sand and scale. The abrasive action removes the mold sand, scale, and burrs. There are several methods for propelling the abrasives used in blast cleaning and a great variety of abrasive mediums may be used. The common abrasive mediums used in foundry application are sand, grit and shot. Grit consists of angular metallic particles and the round metallic particles form the shot.

Two basic methods employed for blasting are:

1. Mechanical blasting, in which the abrasive is propelled by means of a power-driven, rapidly rolling bladed wheel.
2. Air blasting, in which the abrasive is propelled through a nozzle by compressed air.

Of the two methods, mechanical blasting is the more widely used in foundries.

Various shot blast machines are available including rotary tables, tumbling units, rotary drums, continuous cabinet types, portable hand-operated units, and cleaning rooms for very large castings. An illustration of a commonly used cabinet type shot-blast unit is shown in Exhibit IV-27.

(c) Heat Treating

Iron castings are heat treated to improve physical characteristics and to improve machineability. Typical heat treating temperature ranges for gray iron are:

Stress Relief	1000°-1250° F
Anneal	1250°-1725° F
Normalize	1725° F
Quench and Temper	1550°-1600° F

Annealing of white iron castings to produce malleable iron is done at 1600°-1750° F. Batch-type or continuous furnaces may be used depending upon the type of heat treating and production requirements.

(d) Casting Finishing

Following surface cleaning and heat treating, castings are finished to remove gate and riser pads, chaplets, wires, parting line flash not a part of its final dimensions. Chipping hammers and grinders are used for these operations.

Castings that can be handled manually are trimmed or ground on bench, floorstand, or portable grinders. Swing-frame or portable grinders are used for trimming castings that are too heavy to be carried or held by hand.

Tumble finishing may be used in providing final finish on some castings. This process involves the tumbling or rolling of parts in rotating barrels or the agitation of parts in shaker containers. Vibratory tubes or other comparable equipment for cleaning, shine rolling and burnishing are also used.

(e) Casting Coating

The large majority of iron castings are ready for shipment after finishing operations are completed. Some casting specifications, however, require that a surface coating be applied for rust proofing or other reason. Rust preventive paints are usually applied by spraying, fogging, or dipping, depending upon the type of coating, casting size and shape, and production requirements.

The painting facility may include conveyors, spray booth, dip tank, a conveyor system, and a drying oven.

Coremaking

Cores are normally made of silica sand and organic or inorganic binders. The selection of the core formulation and process best suited to a particular application requires consideration of many factors including green strength, dry strength, porosity, core complexity, quantity of cores required, and raw material, equipment and production costs.

(a) Core Processes

The major coremaking processes in current use for castings are:

- Oil Sand Cores
- Shell Cores
- Silicate Bonded Cores
- Furan Cores
- Hot Box Cores
- Alkyd - Isocyanate Cores
- Phenol - Isocyanate Cores

Oil sand cores are widely used although silicate and resin bonded cores are being used in greater numbers each year. Vegetable or mineral oils are commonly used as binders. Cereal binders and clay are often used in conjunction with core oils. The cereal binders, mostly derived from corn, are added to improve green and dry bond, decrease the oil required, and improve collapsibility of the core. Clay is often added in small amounts to increase the green strength.

Shell cores for iron casting are usually made with phenol-formaldehyde resin and round grain silica sand. Large users of shell core sand find it economical to buy bulk resin and coat the silica sand themselves. Premixed sand and resin is available commercially for the smaller user for whom this is not economical.

Hollow shell cores are made by the investment process, and small, solid cores can be made in a hot box machine. No oven is required for shell cores since they cure quickly in the coremaking machine.

Silicate bonded cores are made in a molding or core blowing machine, and set by the application of carbon dioxide in a manner that permits the gas to completely permeate the core. Since the storage life of silicate bonded sand is short when exposed to the air, due to absorption of CO_2, the mixed sand must be stored in covered containers.

Furan air-set cores employ resins made from furfuryl alcohol, ureas, and formaldehydes. The resins are mixed with core sand and a phosphoric acid activator in conventional mixing equipment.

Hot box core resins include furfuryl alcohol, urea-formaldehyde and phenol urea-formaldehyde. The liquid resin is mixed with the core sand and activated in conventional mixing equipment. An exothermic reaction between the resin and the activator progresses quickly when the mixture enters the heated core box in a core blower.

The alkyd-isocyanate process involves the use of a synthetic oil binder which, when mixed with sand and activated chemically, produces cores that cure at room temperature. The key to the process is the polymerization reaction that provides advantages in terms of time and thoroughness of set.

Phenol-isocyanate is a new no-bake process that was introduced in 1970 and is based on a urethane resin system. One type of process consists of a binder and catalyst used in equal portions. An advantage of this process is that strength and hardness properties are obtained at binder levels lower than with other systems.[12]

(b) Core Department Process Flow

Exhibit IV-15 illustrates the process flow for the making of sand cores. Sand is purchased in bulk quantities and shipments are stored in silos or bins. Small quantities of core premixes, resins, binders and other additives are received in bags or drums and stored indoors.

The sand storage bin is often located above the mixer to permit discharge to a weigh hopper directly above the mixer inlet. Other dry and liquid materials are measured by weight or volume and added to the mixer at the appropriate point in the mixing cycle. The core sand mix is discharged from the mixer and transferred to the core machines by conveyor or tote-box.

The selection of the proper machine for forming the core will be determined, in part, by the type of sand mix employed, such as shell or hot box mixes which require specially designed equipment for core box investment and heating. Other processes permit the use of a variety of machines. Simple cores required in small quantities are made manually at a core bench using a wooden or metal core box. Cores with a constant cross section can be made in the desired length in a powered or hand-operated extrusion machine. Molding machines of all types including rollover, jolt and squeezer machines, and sand slingers are still in use in many foundries, but the use of core blowing and shooting machines has become more widespread in recent years except for large cores.

After forming, those cores that achieve a primary or complete set while in the core machine require no special handling since they have sufficient structural strength to permit placing on storage racks or in tote pans for storage or further processing. Cores requiring an oven bake or gasing are placed on a flat core plate or a formed core dryer providing rigid support.

Oil sand cores requiring baking are transferred to gas or oil-fired ovens. Light oil fractions and moisture in the sand are evaporated, followed by oxidation and polymerization of the core oil.

Core finishing operations consist of cleaning, sizing, and assembling. The cleaning operations include trimming, brushing, coating, mudding, and venting. The trimming and brushing removes fins and excess sand. Core coatings, or washes, improve the surface of the casting and insulate the cores from the molten metal.

Holes or depressions in a core are filled and, if additional vent holes in the core are required, they are made at this point.

Sizing of cores includes gaging of the core and filing or grinding to the required dimensions.

Complex cores sometimes require that they be made in separate parts and assembled into final form with core pastes. Occasionally other methods of fastening cores together are used such as bolting.[13]

Pattern Making

Foundry patterns are normally made of wood or metal. Patterns for small production runs tend to be the former and for large production runs, the latter. Wood patterns generally have a shorter useful life, although they can be repaired more easily than the metal patterns which usually have a higher first cost. A large production requirement, however, often results in a lower pattern cost per mold with metal molds.

Typical pattern making steps include cutting the wood or metal pieces to size, fastening the pieces together, and painting, varnishing and mounting where required. Match plates are often cast from the original patterns.

Wood pattern shop equipment includes different types of saws, planers, joiners, lathes, edgers, routers and drill presses. Metal pattern making equipment includes typical machine shop tools.

REFERENCES

1. U.S. Department of Commerce News, Business and Defense Services Administration, BD 69-14, March 13, 1969.

2. A Systems Analysis Study of the Integrated Iron and Steel Industry, Division of Process Control Engineering, National Air Pollution Control Administration, Department of Health, Education and Welfare, Battelle Memorial Institute, May 15, 1969.

3. The Cupola and Its Operation, published by the American Foundrymen's Society, 3rd ed., 1965.

4. Metals Handbook: Volume 5 Forging and Casting, published by the American Society for Metals, 8th ed., 1970.

5. "Continuous Iron Melting," R. S. Amala and J. B. Walker, Modern Casting, May, 1970, p. 45.

6. "Some New Factors Affecting Cupola Operation," H. W. Lownie, Modern Casting, 1966.

7. Principles of Metal Casting, R. Heine, McGraw-Hill Book Co., 1955, pp. 550-553.

8. "Comparing Processes for Making Ductile Iron," Dr. E. Modl, Foundry, July, 1970, pp. 42-48.

9. Molding Methods and Material, published by the American Foundrymen's Society, 1st ed., 1962.

10. Casting Materials Company.

11. "Beat Hot Sand Problems with Absorption Cooling," A. J. Wagner, Modern Casting, August, 1970, p. 46.

12. "Progress in Coremaking," W. O. Ferguson, Foundry, August, 1970, pp. 53-59.

13. Foundry Core Practice, H. Dietert, published by the American Foundrymen's Society, 3rd ed., 1966.

V - EMISSIONS PRODUCED AND EMISSION CONTROL CAPABILITY

EMISSIONS PRODUCED IN THE BASIC PROCESSES

Emissions consisting of particulate matter, fume, smoke, or gas are a by-product of every foundry process and almost every foundry operation. It is necessary that the source of these emissions and the factors affecting their type and quantity be identified so that the foundry emissions problem can be evaluated.

The type, concentration, and size of typical foundry emissions are tabulated in Exhibit III-7 by department and operation. These emissions are identified in the following paragraphs and evaluated in a later section of the report.

Raw Material Storage and Charge Makeup

The handling, preparation, and charge makeup of the basic foundry raw materials--scrap metal, coke, and limestone--may produce emissions in a variety of ways. The storage of coke and limestone over extended periods may result in the disintegration of these materials from the action of the sun, rain, and repeated freezing and thawing. Ferrous scrap rusts rapidly. Subsequent handling during the makeup of furnace charges may cause limestone dust, coke breeze and small quantities of rust to be released into the environment. At conveyor transfers, as well as storage bins, weigh hoppers and the location where these materials are placed in charge buckets, emissions tend to increase due to tumbling of the material. Rehandling of coke results in additional disintegration and, to a lesser degree, this is also true of limestone.

The preparation of metallic charge materials including the breaking and cutting of large scrap, removing cutting oil residue from machine shop turnings and borings in preparation for briquetting, and cleaning of foundry returns represent an additional potential source of emissions. The industry trend, at least for the larger foundries, is to purchase scrap to definite specifications to eliminate the need for scrap preparation by the foundry, except for foundry returns. A few foundries make briquettes from internally generated turnings and borings, but most companies in this position sell the turnings and borings and purchase briquettes according to their needs. For the foundry that does convert its machine shop scrap into briquettes, the removal of oil on the turnings represents a source of potential emissions if the scrap is incinerated, and to a much lesser degree if the scrap is centrifuged. Shot blasting of foundry returns may produce emissions in the form of dust from the embedded sand and from broken shot. Shot blast machines are normally furnished with dry mechanical collectors or fabric filters.

Melting

The melting department is responsible for the greatest amount and heaviest concentration of emissions in the foundry, producing the need for control equipment on cupolas, electric arc furnaces, preheaters and dryers. Emissions from coreless induction furnaces are insignificant due to the quality of scrap and the fact that no combustion takes place in the units. Channel induction furnaces also produce minimum amounts of emissions and are seldom provided with emission control equipment.

The cupola is the largest single source of emissions, producing fume, smoke, particulate matter and gas. Concentrations are affected by the quality and quantity of charge materials, the use of techniques such as oxygen enrichment and fuel injection, the volume and rate of combustion air, and the melting zone temperature.[3]

The electric arc furnace produces somewhat less emissions than the cupola because no fuel or combustion air is required. Combustion in an arc furnace is limited and results from the inclusion of combustible elements in the charge and from burning of the electrodes. Concentrations may be great enough, when used as a prime melter, to require emission control equipment. Emissions include smoke, fume, dust, and possibly some oil vapors in concentrantions that are affected by the quality and composition of charge materials and the temperature of the bath. Emissions are greatest during the melt-down phase of the cycle, and less after melting is completed, when the molten metal is covered with slag.

Induction melting produces light concentrations of emissions consisting of fume, smoke, and oil vapor. Control devices are usually not provided or required. The smoke and oil vapor usually derives from small amounts of cutting oil adhering to the steel or iron scrap, and can be eliminated by preheating prior to charging into the induction furnace.

The reverberatory or air furnace for melting or duplexing produces light to moderate concentrations of emissions. Combustion occurs within the furnace but the gas or oil fuel is burned in highly efficient burners above the metal bath. Smoke and fume are produced in this type of furnace. The smoke results from combustion of oil on the scrap and other combustible materials in the charge. Metallic oxides appear in the emissions as in any melting furnace, and are the result of nonferrous contaminants in the charge material, vaporized in the molten bath with a portion of the iron scrap. The concentrations are related to the partial pressures of the oxides at the melting temperature.

Preheaters or dryers for furnace charges are another source of emissions in the melting department. They are rarely used in conjunction with cupolas or reverberatory furnaces since these are highly efficient preheaters in themselves. The use of a preheater as a means of increasing melting capacities of electric arc and induction furnaces, and to insure dry furnace charges essential to the induction furnace, transfers the majority of the emissions production from the furnace to itself by burning combustibles which would otherwise burn in the furnace. The resulting emissions are therefore the same type and appear in the same quantity as would be found in these furnaces without preheating.[4]

Coreless induction furnaces used as holding or superheating furnaces charged with molten iron emit minor amounts of metallic oxide fume and are rarely provided with emission control equipment.

Magnesium Treatment for Producing Ductile Iron

Treatment of molten iron with magnesium compounds to produce ductile iron is a significant source of foundry emissions. Emissions from this operation consist primarily of magnesium oxide representing up to 65% of the metal injected. The high loss occurs since the boiling point of magnesium is far below the temperature of the molten iron. The reaction is often violent, depending on the form of magnesium used, and shielding or enclosing of the ladle at this time is recommended for this reason as well as to insure maximum collection with a minimum dilution with infiltrated air.

Molten metal in a furnace or ladle produces a shimmering heat wave above its surface which is often mistaken for emissions rising from the bath. The phenomenon is an optical illusion resulting from the varying index of refraction of the unequally heated air strata, and is present where molten metal is used.

Molding, Pouring and Shakeout

The molding operation is not a major contributor to foundry emissions. In green sand molding, moisture in the sand acts as a dust suppressant. Small quantities of dry parting compound are emitted when the mold halves are dusted with this material. Liquid partings used to prevent molding sand from sticking to metal patterns or match plates have a kerosene base. When sprayed on the patterns, a portion of the vehicle vaporizes, and the solids such as stearic acid are sprayed into the air in the immediate environment. Sea coal is also used as a mold spray and is released into the atmosphere. Concentrations are very light.

Emissions from the pouring operation are much more severe than from molding and are usually more difficult to capture. The hot metal, when poured into the mold, first ignites and, as oxygen in the mold is exhausted, thermally degradates such materials in the sand as sea coal, cereal and synthetic binders, and core binders. Steam is formed in green sand molds from the moist sand.

In the full mold process, the complete pattern is consumed. Concentrations are usually relatively low for a single mold, but the multiplicity of molds produced increases the severity of the problem. Most of the emissions are steam, vapor, and smoke. In the full mold process and for many of the synthetic binders, emissions may be toxic, and only the low concentration per mold, coupled with general foundry ventilating systems, prevents physiological reactions in molders, pouring crews and shakeout men. Examples of potentially toxic emissions are styrene, low molecular weight polystyrene, ethylbenzene, methyl chloride, chlorine, hydrogen chloride and decomposition of evaporative products in addition to CO, CO_2 and H_2O.[1]

The pouring of ductile iron results in further emissions of magnesium oxide from the magnesium treatment process. The concentration of smoke, fume, gas, and vapor is related to the hot metal temperature, length of time between pouring and shakeout, and the quantities of binders, moisture and parting compounds in the molding sand.

At the shakeout, the action of separating castings from molds brings hot castings into contact with moist molding sand not adjacent to the sand-metal interface at the time of pouring. This results in additional smoke, steam and vapor of the same type emitted during the pouring operation. Concentration of emissions is momentarily high, but the casting is cooler than the molten metal while pouring, the sand is quickly separated from the casting, and the emissions are often able to be contained and removed through the use of ventilated hoods.

Sand Conditioning

New molding and core sand are ordered to a desired screen test for specific use and always include some fines. The escape of fines into the atmosphere varies with the method of handling. Closed systems such as pneumatic conveyors release only small amounts and are provided with exhaust connections at the inlet and the receiver. Systems using belt conveyors and bucket elevators for dry sand may release fines and dust at transfer points between conveying units. Many smaller foundries unload and transfer sand to floor level bins manually, or with front-end loaders. Load and unload points are generally uncontrolled. The handling of conditioned molding or core sand presents fewer problems than new sand because of the moisture content and binder additives and therefore control equipment and hoods are generally not required. Shakeout or return sand produces more emissions because it has been partially dried from contact with the hot metal. Introduction of fresh spill sand from the molding floor and excess prepared sand helps considerably in cooling, moistening and decreasing dust and fines from being released to the atmosphere. It is considered good practice to enclose the transfer points of conveyor systems handling dry sand, and to provide exhaust connections at these locations and at the vibrating or rotating screen and the return sand storage bin.

Moderate concentrations of fines, dust and binder materials are emitted at the sand mixer. Concentrations are increased if the muller is equipped for sand cooling. This is accomplished by directing a blast of cooling air either over or through the sand while it is being mixed. The air blast entrains small particles and must be exhausted to a control device to separate the dust from the air blast.

Cleaning and Finishing

Cleaning and finishing operations produce emissions less troublesome than other foundry processes. Particulate matter is generally larger and easier to capture and separate from the air stream even though concentrations can occasionally be moderate to heavy. The metallic dust and particles removed from grinding operations have a high density permitting the use of less expensive dry mechanical collectors but require higher entrainment velocities for removal from the working surface. Particulate concentration is dependent upon type and surface speed of the grinding wheel and the amount of pressure exerted by the grinder. Chipping operations produce such large particles that control equipment is not required except when chipping castings with burnt-in sand. In this event, good foundry practice dictates the wearing of a face mask. Abrasive shotblasting produces high concentrations of metal particles, sand dust, and broken shot but modern blast machines are provided with high efficiency fabric filters designed for the purpose. The concentration of these emissions is a function of the quantity of embedded sand on the castings, fracture strength of the shot, and length of time in the blast cabinet or room. Sand blasting, now seldom used, produces high concentrations of sand dust with concentrations related to air pressure, blast sand characteristics and length of time required for cleaning. Sand blast operators wear ventilated hoods to prevent inhalation of sand dust.

Emissions from annealing and heat treating furnaces are minimal except when the castings have previously been oil quenched. Concentration of the resulting smoke is a function of the amount of oil residue on the casting surfaces. Painting is infrequently done by foundry departments. Emissions from this operation consist primarily of vapors from thinners and concentrations depend on the type and quantity of the volatiles.

Coremaking

Emissions problems in the core department are similar to those encountered in the handling of molding sand. No major difference exists for the handling and storing of new sand. The coremaking operation using synthetic binders and heated core boxes often results in vapor and gases; some of them may be toxic or acrid in nature. A similar situation exists in some of the synthetic binders that set at room temperatures, and to a lesser degree with oil sand coremaking. Oil sand cores require oven baking to dry and polymerize the oil binders. Core oven emissions can be highly odorous. Incineration is the most satisfactory way to control these emissions, using afterburners or catalytic combustion chambers. Concentrations of the emissions vary with the type of binder used.[2] With the wide variety of binders now available and others in the development stage, conservative and flexible design criteria for collection ductwork and control systems would be recommended.

Pattern Making

Wood pattern shop emissions consist primarily of wood dust and chips. Concentration can be high for each machine tool but normal utilization factors of the machines reduce the system capacity. The wood dust, having a low density and large surface area, is easily entrained.

EMISSION CONTROL CAPABILITY

The current state of the art of foundry emissions control does not fully satisfy the needs of the industry. Although, on a purely technical basis, virtually all particulate and most gas, smoke and fume emissions can be controlled, the cost of such control for several basic foundry processes is often beyond the financial ability of the small- and medium-sized foundries, which comprise the large majority of the industry, to support. The current foundry need is for the development of equipment to control emissions from cupolas, electric arc furnaces, ductile iron production by magnesium treatment, mold pouring stations, and coremaking operations at costs that do not threaten the profitability, and even the existence, of the small foundry.

Emissions Controllable with Existing Equipment Design

Relative controllability of foundry emissions is indicated in Exhibit III-7 on a comparative basis. Emissions more difficult to collect are by and large those with large concentrations of very fine particles, five microns and smaller. Conversely, emissions easier to collect are those consisting entirely of large particles.

Particulate Emissions Uneconomical to Control

Generally, all foundry emissions are uneconomical to control, since the collected material has little or no value, and its collection adds no value to the foundry's product. The installation and operating costs of control systems vary over a wide range, and it is necessary to identify those operations requiring highly uneconomical systems beyond the financial capability of the majority of foundries.

The cost of an emissions control system depends on the following variables:

- Properties of emissions, including size distribution, density, chemical composition, corrosiveness, solubility, combustibility, and concentration.
- Difficulty of capturing the emissions in an air, gas, or water stream of moderate temperature and volume.
- Difficulty of separating emission particles from the captor medium.

Properties of the matter to be collected are generally fixed by the process and raw materials, although modification of the equipment could possibly alter the properties. Assuming them to be fixed for a given operation, the first consideration is the cost of capture. If the operation occurs in an enclosed and fixed location such as a melting furnace or oven, capture may be relatively simple and may be accomplished at low cost although emission collection and separation costs could be high. If the location of the operation is not fixed and occurs in the open, such as pouring of molds set out on the foundry floor, then capture is difficult and more expensive. In the latter case, with pouring emissions dispersed throughout the plant, much of the air in the building must be processed through the control system to collect the emissions. A system of this capacity would be expensive to install and operate.

The third factor of system cost is the difficulty of particle separation from the captor medium. Large, dense particles, such as metallic fragments from grinding operations, can usually be separated by the use of relatively low cost dry centrifugal collectors. Submicron-sized metallic oxide particles from a melting furnace, however, require more costly collection equipment such as high energy wet scrubbers or fabric filters.

An analysis of foundry operations identifies processes combining difficulty of emission capture and collection with high cost of the control equipment. These are briefly discussed below while an evaluation of these emissions are presented in Section VI and relative costs are tabulated in Exhibit III-7.

(a) Cupola

Iron melting in a cupola produces heavy concentrations of particulate emissions in a gas stream up to 2000° F. In most cupolas, large amounts of air are infiltrated through the open charging door greatly increasing the cost of the control system, since the size and cost of a collector is directly related to the volume of gas to be handled.

(b) Electric Arc Furnace

The electric arc furnace when melting iron produces moderately heavy concentrations of particulates with a large percentage of the total particles below five microns in size. The gas stream is well over 2000° F, requiring cooling by infiltrating air or by water sprays.

(c) Magnesium Treatment for Producing Ductile Iron

This process results in heavy concentrations of extremely fine metallic oxides, principally magnesium oxide.

(d) Mold Pouring

Mold pouring produces only moderate concentrations of emissions, but in many foundries capture is very difficult. In addition, the emission may be toxic or acrid.

(e) Coremaking

Coremaking and baking or heating for setting of the binders result in moderate concentrations of sometimes toxic and acrid emissions. Smoke and vapors from floor or coremaking operations are difficult to capture with only moderate dilution and are therefore expensive to control. Core baking oven emissions can be controlled with afterburners or catalytic combustion chambers.

These five processes represent the sources of foundry emissions not readily controllable, or highly uneconomical to control.

REFERENCES

1. Conference on Foundry Ventilation and Dust Control, Harrogate, England, 1965. British Cast Iron Research Association, Alvechurch, Birmingham.

2. Foundry Core Practice, H. W. Dietert, American Foundrymen's Society, Des Plaines, Illinois, 3rd ed., 1966.

3. The Cupola and Its Operation, American Foundrymen's Society, Des Plaines, Illinois, 3rd ed., 1965.

4. Air Pollution Engineering Manual, U. S. Department of Health, Education and Welfare, Publication 999-AP-40, 1967.

VI - QUANTIFICATION AND EVALUATION OF EMISSIONS

DESCRIPTION OF SAMPLING AND ANALYTICAL TECHNIQUES

Measurement or sampling of emissions from a foundry source can be conducted in the general atmosphere near the suspected source or in a specific stack. The sampling alternative used depends on the objectives of the measurement which include:

1. Determining whether stack emissions are in violation of existing ordinances.
2. Providing a guide in selection of proper control equipment.
3. Evaluating the effectiveness of control equipment after installation.

Various techniques and methods are available for sampling emissions in the atmosphere or stack, and the adequacy and effectiveness of these methods vary widely depending on which one is employed.[1]

General Atmosphere Sampling

Many different area or atmosphere sampling methods are used in various sections of the country. Normally, the concentration of dust collected by area sampling methods is reported in micrograms per cubic meter and coarse dust fallout in tons per square mile per month, pounds per 1,000 square feet per 30 days, or as a soiling index. Such samplings are conducted off the premises of a particular plant and a local agency procedure is followed rather than one related to a specific industry.

Various factors such as frequency of sampling, wind, humidity, topography and analytical procedures are important, no matter which method is used to sample contaminants in the general atmosphere.

Usually, particle fall is best determined by frequent short time cumulative samplings rather than one continuous cumulative sampling over a long period of time. The summation of a series of samples can produce data approximately as accurate as, and more economically than, a continuous sample.

Meteorology factors such as wind and humidity, and also topography observations including the relation of differences in surface elevation of the surrounding area, hills, valleys, terrain and buildings, must be recorded when atmosphere sampling of emissions is made.

How the sample data will be analyzed, and the type of equipment used, must be determined prior to sampling so that the proper sampling procedure is pursued. The adequacy of any quantitative general atmosphere sampling method is limited because of the effects which diffusion, turbulence, wind velocity, wind direction and various other factors have on measurement results.[1]

In addition to the quantitative methods discussed, discharge quality can be estimated by observing the opacity or discharge appearance from a stack. Opacity scales of light obscuring degree, an adaptation of the Ringelmann Scale, are often referred to in air pollution codes.

The Ringelmann Scale shown in Exhibit VI-1 is a chart for grading the black density of smoke from exhaust stacks and has been used in the United States since the early 1900's. The scale was originally designed for the purpose of indicating the degree of combustion control in coal burning equipment. It was not designed to cover metal melting emissions.

With the Ringelmann Scale, an observer compares smoke emission to the chart and estimates black density of the smoke. This method relies entirely on the personal evaluation of an observer when viewing stack discharge. Because smoke emission colors other than black also occur, variations of the Ringelmann Scale have been developed which refer to an equivalent opacity rule. This rule states that if an emission, regardless of color, obscures an observer's view to such an extent that smoke of a given Ringelmann number would, the emission is equivalent to a smoke plume of that number.

Metallurgical processes such as iron melting often emit particulate matter down to one micron or less in diameter. These small particles often exhibit light scattering effects, and cause the appearance of a high level of opacity when emitted from an exhaust stack in a gaseous stream. When the Ringelmann Scale is used to determine concentration or weight of particulates in metallurgical process exhausts, the presence of these submicron particles tends to lead to erroneous conclusions.

Some air pollution control regulations specifically limit the discharge of visible emissions in addition to limiting particulate concentrations of those emissions. For these regulations the legal criterion is the Ringelmann equivalent opacity test, even though the application of a visual test for compliance is subjective and its reproducibility subject to atmospheric conditions. Some other state air pollution boards have adopted statements such as the following regarding the use of a Ringelmann Scale: "The Ringelmann chart shall be used for grading the light obscuring power of smoke. It shall not be used for determining metallurgical fume emissions or measuring the opacity of non-combustion process emission." However, it is a simple and rapidly applied test that will probably continue to be used for judging compliance to visible emissions standards until such time as test devices are developed that provide reliable, inexpensive and reproducible results.

Stack Sampling

The collection of representative samples of gaseous and particulate matter flowing through a stack requires specialized equipment, skills and knowledge and therefore is a more complicated procedure than general atmosphere sampling. More than one sampling method is usually used when sampling mixtures of particulate matter and gaseous compounds, especially if separation of the sample is required.

Of the number of methods presently in use for stack sampling, those developed by the American Society of Mechanical Engineers are the most widely employed. The ASME has published two Power Test Codes--(1) PTC 21-1941 "Dust Separating Apparatus" and (2) PTC 27-1957 "Determining Dust Concentration in a Gas Stream"--which are followed when the effectiveness of an emission control equipment system is evaluated and/or to determine if an ordinance has been violated. An adaptation of the ASME Codes with special emphasis on the specific problems of testing foundry cupolas has recently been adopted by the American Foundrymen's Society and the Gray and Ductile Iron Founders' Society, Inc. The recommended practice is discussed later in this section, and a copy is included in Appendix E. The data presented in this report are from cupola tests made according to the provisions included in the ASME Codes and were run before the adoption of the recommended practice.

The ASME lists four basic steps to follow in evaluating the effectiveness of an emission control equipment system:

1. Secure a representative emission sample.

2. Filter and measure the dust contained in the sampled gases.

3. Measure the sampled gas volume.

4. Measure dust conditions such as temperature, pressure, composition and various other factors.

In following this four-step procedure, agreement must be reached by the parties to the test on certain pertinent items. A listing of these items appears in Exhibit VI-2.

The ASME provides a number of tables to report and analyze test results, major headings of which appear below.

- General Information.
- Description, Dimensions, etc.
- Test Data and Results.
- Pitot Tube and Dust Samples Data.
- Dust Caught by Separator.
- Size Analysis of Dust Samples.
- Efficiencies.
- Fuel and Gas Analyses.
- General Data

There are 69 lines of data called for in the above nine tables. The code manual, PTC 21-1941, can be referred to for a complete description of all test procedures including tables for reporting results.[1, 2]

The ASME procedures described in PTC 21-1941 and PTC 27-1957 were followed by the foundries visited where emission test results were obtained.

The ASME test procedures on dust concentration and dust separating equipment are adequate and will produce accurate results if followed by a trained team of specialists.

Of particular importance in any stack sampling method is determination of emission particle size since these data will largely determine overall collection efficiency of a control equipment system. Considerable care must be exercised in collection of samples so that agglomeration and shattering of particles will not occur. Particles 44 microns and larger in size are normally separated by standard screens. Particles passing through the 325-mesh screen (44 microns or smaller) can be estimated or quantified by one of several methods.

1. Microscope Counting - A small portion of the dust sampled is suspended in a suitable liquid medium and placed in a dust counting cell where the particles in each size range are counted. The ranges vary but separations of up to 5, 6-10, 11-20 and 21-44 microns are usually made.

2. Settling Method - A sample of the collected dust is suspended in alcohol in a beaker. Separation is then made by filling the beaker to a mark 8 or 10 centimeters from the bottom, stirring until completely mixed, letting stand for a specified time and quickly siphoning off the liquid down approximately 6 centimeters below the starting level. The settling time is computed to give the size range desired and the operation is repeated approximately three times. The particle size range is then checked by microscope in a dust counting cell and the dust particles are separated either by filtration or by centrifuging for drying and weighing.

3. Centrifuge Separation - This technique essentially consists of separating one-gram samples of dust into sizes. The specialized test equipment required is manufactured in Sweden.

4. Air Elutriation - This method consists of separating microscopic particles into size ranges by air elutriation.[1]

NECESSITY FOR STACK SAMPLING PROGRAM

Test Reports Gathered and Analyzed

Emissions data from 45 stack sampling tests tabulated in the foundry data bank were available for the evaluation of cupola emissions as functions of furnace design and operating variables. The data were obtained from foundry operators during plant visits, testing laboratories, equipment manufacturers, state pollution control boards, and published literature. Stack sampling tests were not conducted specifically for this study. The collected data were not adequate to completely define and quantify the effect of all melting variables on emissions levels. The analyses did, however, identify certain design variables that have no significant effect on emission levels and a number of variables having either a quantifiable effect or a definite, if not completely defined, effect on emissions levels.

Need for Additional Data

Additional testing of cupolas would be required to definitely establish mathematical relationships between all operating variables and emissions rates. The program to achieve this purpose would require the use of experimental cupolas of several different sizes operating under laboratory conditions. It has been determined that the results of such a program, while of considerable future interest, are not essential for the formulation of the recommended research and development projects developed in this study, and for the completion of this report.

EVALUATION OF CUPOLA EMISSIONS

Nature of Data Gathered

The evaluation of cupola emissions and the development of emission levels as a function of cupola design factors and operating practices required analysis of three types of input data: the design criteria for each cupola considered, the actual operation at the time the stack tests were made, and the emission data at the cupola outlet, or control system inlet.

Detailed information on a total of 481 iron melting systems in 1968 foundries is tabulated in the foundry data bank. Cupola furnace installations represent 329 of this total. The cupolas are classified according to type of lining, blast air, charging, gas take-off, and use of afterburners, oxygen enrichment, and fuel injection. In addition, the data bank lists cupola dimensions, capacities, blast air volumes and temperatures, afterburner sizes and locations, and other appropriate data required to specifically describe the installation. Operating practices, including charge makeup, type and condition of scrap, and coke, are also shown.

Particulate emission levels, while commonly reported in various ways, are tabulated in the data bank in terms of grains per standard cubic foot of gas, and for the analysis, are converted to pounds per ton of metal melted. This form removes the effect of varying amounts of infiltrated air on concentrations of particulates. Emissions listed in the data bank show control equipment inlet and outlet concentrations as follows:

Test Location	Number Reported
Inlet concentrations only	31
Outlet concentrations only	70
Inlet and Outlet concentrations	22

The amount of emission data available from the foundries included in the data bank is limited even though the foundries were selected on the basis of either having control systems already installed or in the late planning stage.

A number of factors result in the limited amount of data available.

1. Foundries are often reluctant to disclose the results of stack testing, even on a non-identification basis, when the results indicate that the control equipment is either not meeting the applicable code, or is just barely meeting it.

2. Because of the high cost, few foundries care to pay for stack testing to determine particulate concentrations from uncontrolled cupolas already known to violate the code, preferring instead to invest those funds in the control equipment.

3. Equipment manufacturers do not, as a rule, require cupola emission levels when quoting control systems. Equipment designs are generally based on years of experience and rules of thumb, with design contingencies usually large enough to cover variations in type and quantity of emissions from one installation to the next. Testing of only the final emission is performed following equipment installation to prove that contract guarantees have been met.

4. Stack sampling tests are expensive, and few tests are made without a compelling need.

5. Stack testing required by the various emissions control boards to prove compliance with local or state codes are at the expense of the foundry. Since the control board is concerned only with emissions from the control system, this is by and large the only location in the entire melting and control system that is tested.

For certain systems, such as fabric filters and high energy wet scrubbers known to be operating properly in the 99+% efficiency range, the inlet concentration can be estimated very closely from the collector outlet emission level, or the amount of material collected. This is not feasible with dry centrifugal, low and medium wet scrubbers, or wet caps where the total efficiency can vary as much as 20%

depending on the type and particle size distribution of the particulate matter.

Classification of Melting Processes by Type and Design Parameter

The features of melting furnaces are organized in an orderly format to provide a basis for evaluating the foundry data gathered from various sources. The furnaces are classified initially by type--cupola, electric arc, electric induction, and reverberatory or air furnace. The first three types of melters are further divided by design parameters to produce the "family tree" patterns indicated in Exhibits VI-3, VI-4, and VI-5. Each path from the top to the bottom of the exhibits represents a theoretical classification. An eleven-digit code describing each possible classification is used in order to facilitate identification of the system, and for ease in retrieval of information from a computerized data bank. A description of the code is included in Appendix B.

Most theoretical combinations of furnace design parameters are either impractical or mutually exclusive, and do not exist in practice. Exhibit VI-6 shows the 32 cupola classifications identified as practical designs in current use. The tally marks indicate the distribution of existing cupola designs among these 32 classes, for the furnaces in the data bank for which emissions data were obtained. The tally marks are not necessarily additive.

Variables Affecting Emissions

Exhibit VI-7 portrays the major components of particulate emissions from iron melting cupolas and the percentage by weight of the various materials determined by chemical analysis of emissions from seven cupolas. The nine components can be grouped into three major categories: (1) metallic oxides, (2) silicon and calcium oxides, and (3) combustible materials.

It has been reported that the amount of metallic oxides occuring in cupola emissions is related to the presence of the respective metals in the scrap charge and their partial vapor pressures at the temperature of the cupola melting zone.[3] All metallic oxides except those of iron indicate the presence of nonferrous contaminants or alloying additions in the metallic scrap. For example, zinc oxide could result from the presence of galvanized scrap or from die castings, lead oxide from terne plate, aluminum oxide from aluminum scrap, and chromium, copper and cadmium oxides from plated materials. Iron oxides are always to be found in cupola emissions, the concentration dependent on such factors as scrap thickness, degree of surface corrosion, and temperature in the melting zone.

The oxides of silicon and calcium, representing the second category, result from lining erosion, embedded molding or core sand on foundry returns, dirt from the scrapyard adhering to scrap, or from the limestone flux.

The third category of emissions, combustible material, includes coke particles, vaporized or patially burned oil and grease, particles from fabric coatings from automotive scrap, and other similar contaminants swept up the stack by the top gases.

The range of concentrations of the emission components reported by the seven foundries listed in Exhibit VI-7 is in general agreement with other reported data as shown below.[4]

Chemical Composition of Cupola Dust

Component	Mean Range	Scatter Values
SiO_2	20%-40%	10%-45%
CaO	3- 6	2 -18
Al_2O_3	2- 4	0.5 -25
MgO	1- 3	0.5 - 5
FeO(Fe_2O_3,Fe)	12-16	5 -26
MnO	1- 2	0.5 - 9

In addition to the presence of these materials in the furnace charge and the temperature of the oxidizing atmosphere in the melting zone, other variables would be expected to influence the amount of cupola emissions. Specific blast rate, when increased, would be expected to result in greater emissions by entrainment of metallic oxides and mechanical dusts, such as coke and limestone. A portion of the entrained particles is filtered out of the gas stream by the burden, with a higher burden offering greater opportunity of particle capture. It is well recognized that emission rates are greater during burn-down, due in part to increased temperatures resulting in larger gas volumes, higher gas velocity, lower collecting ability of the smaller burden height, and possibly greater formation of metallic oxide vapors in the melting zone. Furthermore, the height of the reducing zone is shorter, with less potential for reduction of the already formed oxides.

It would be further expected that cupola emissions would vary directly as the percent of coke in the charge, and some researchers have reported such a trend.[4] This is a reasonable theory since degradation of the coke while weighing, charging, and moving downward in the cupola shaft will result in an increase of coke dust in the furnace. Therefore, any change in operating practice resulting in a decrease in the coke charge, including heating of the blast air, or injection of an auxiliary fuel, should have a beneficial effect on the amount of particulates emitted.

The use of an afterburner, properly designed and installed, will decrease the quantity of combustible particles released to the atmosphere or control system. Sufficient oxygen must be provided through the charging door to permit complete combustion, and the upper cupola stack must extend far enough to permit time for comubstion before the particles are exhausted to the atmosphere or to the emissions control equipment. Deficiency in either factor will tend to negate the potential advantage of the afterburner.

Operating practices have noticeable effects on emissions levels. The use of wood or paper products for igniting the coke bed results in smoke during this part of the operating cycle. Fluctuating burden height can result in higher emission rates. Coke and limestone should be handled carefully to limit degradation, and should be screened prior to weighing in order to limit the addition of dust to the charge. Shotblasting of foundry returns and cleaning of oily scrap will result in lower emissions.

It has been theorized that design of the cupola can have an effect on the type and quantity of particulate emissions. An objective of the study was to determine whether test data analyzed on this basis substantiate the theory. The effort expended to investigate possible relationships between emissions levels and cupola design includes the identification of 32 design classifications representing a large majority of cupola installations in this country, the visits to foundries representative of these classifications, and collection of detailed design, operating and emissions data. Sources of data for this analysis are shown in the table on the following page.

Sources of Foundry Data for Determination of Effect of Cupola Design Parameters on Emissions

	Melting Systems			
Source	Cupola	Electric Induction	Electric Arc	Total
Foundry Visits	29	(1)*	4	33
Interview Guide	8	-	-	8
Only A/P Control Boards	9	-	-	9
Total	46	(1)*	4	50

Note: * This foundry has both electric induction and arc furnaces as primary melters, and is counted only once.

Particle size distribution of cupola emissions indicated by both respondent foundries and by installations reported in the literature are tabulated in Exhibit VI-8. A definitive relationship between size distribution and chemical composition of emissions has not been discovered in the literature search, nor is investigation of the possible relationship within the scope of the study. It would be expected, however, on the basis of other information, that a high percentage of particles less than five microns in size would coincide with a finding of a substantial percentage of metallic oxides. Similarly, a high percentage of particles greater than 44 microns in size would correspond to large amounts of SiO_2 from foundry returns and dirty scrap, and combustibles such as coke breeze.

Analysis of Emissions Data

Cupola design parameters and particulate emission rates for 17 furnace classifications are tabulated in Exhibit VI-9. This is a condensed summary of the melting systems, reported in sufficient detail to permit complete classification of the furnaces. Data from foundries reporting identical, or nearly identical, emission rates from two or more cupolas of the same classification are averaged and the data are reported only once in the exhibit. This averaging prevents undue emphasis being placed on any particular foundry and testing technique. Lining characteristics, blast air temperature and method of heating, charge opening, location of gas take-off, and use of afterburners are considered in the multiple regression analysis to determine the relative effect of design parameters on cupola emission rates. In certain cases where data are limited and furnaces differ only in one or two parameters, forced comparisons are made.

The results of the linear regression analyses show no clear relationships between furnace emissions and any of the cupola design parameters. Two trends, possibly warranting further investigation in the future, are apparent:

1. Eight of the 12 unlined cupolas have emissions above the median rate of 20.8 pounds/ton of melt, while the emissions of the 13 acid lined cupolas are below the median

rate. The two reported emissions rates for basic lined cupolas permit no conclusions to be drawn since one was above and the other below the median.

2. Those cupolas reported as using briquettes in the metallic charges all have emissions rates greater than average of all foundries for which emissions rates are available.

Exhibit VI-10 portrays two correlation matrices from a second series of multiple linear regression analyses. In this series, specific melt rate, specific blast rate, metal to coke ratio, and blast temperatures are compared to particulate emissions to determine the possible existence of correlations. The following units are employed in the analysis:

1. Specific melt rate - Melting rate in tons per hour per square foot area of the melting zone.

2. Specific blast rate - Blast rate in standard cubic feet per minute per square foot area of the melting zone.

3. Metal to coke ratio - Pounds of metallic charge per pound of coke charge.

4. Blast temperature - Degrees Fahrenheit. Exhibit VI-11 tabulates the data for the variables used in the analyses.

The first matrix is the result of data from acid lined cupolas and the second from unlined cupolas. Insufficient data are reported from basic lined furnaces to permit a similar analysis for this classification.

The acid lined cupola matrix indicates a significant correlation between emissions and blast rate expressed by the formula

$$E = .05 + .07\ B$$

where E = particulate emissions in pounds per ton of melt, and B = specific blast rate in SCFM per square foot furnace area. The line represented by this equation is shown on Exhibit VI-12.

The matrix indicates that specific blast rate provides the best correlation with particulate emissions of all variables considered, followed by specific melt rate, blast air temperature, and metal to coke ratio in descending order.

The regression analysis program, after calculating the correlation index of the individual variables, calculates the combined index of the two variables with the highest individual indices. The process is continued by adding variables one at a time in descending order of their individual indices until all have been included, or until the index improvement by the addition of one fails to increase the combined effect by a significant amount.

In this case, the correlation index of 0.6530 for specific blast rate is not improved significantly by the inclusion of specific melt rate in the analysis. This implies that specific melt rate is not an important factor in the generation of particulate emissions.

The second correlation matrix listed on Exhibit VI-10 is for unlined cupola data and indicates a significant correlation between emissions and the two variables, coke rate and specific blast rate, expressed by the formula

$$E = 57 - 6.6\,C + 0.1\,B$$

where E = particulate emissions in pounds per ton of melt, C = metal to coke ratio, and B = specific blast rate in SCFM per square foot furnace area.

The regression analyses indicate that specific blast rate has a significant effect on emission rate for both acid lined and unlined cupolas. Coke rate, however, is of greater importance than blast rate for unlined cupolas and insignificant for acid lined cupolas. No reasonable explanation can be offered for this difference between acid lined and unlined cupola emissions. Additional observations could possibly show a stronger correlation between coke rate and emissions for acid lined cupolas.

Oxygen enrichment and natural gas fuel injection have been presented in recent years as techniques to reduce coke requirements, or to increase melting rates when using the same metal to coke ratio. These techniques have been partially accepted by the industry because of their substantial advantages but little research and development work has been done to date that establishes their effect on cupola emissions. It is possible at this time to report on only one research effort for oxygen enrichment and one for gas injection. No broad conclusions can be drawn from these limited data, but trends demonstrated are believed to be valid.

Over 20 cupolas are identified in the general foundry data as making use of oxygen enrichment to increase the total O_2 content in the blast air from 21% to 25%, commonly reported as 4% enrichment. Only one foundry, however, has reported emissions levels with and without the use of additional oxygen as follows:

Emissions with 4% O_2 enrichment - 1.84 gr/SCF
Emissions without O_2 enrichment - .71 gr/SCF

These emission levels are reported for an 88-inch lined diameter cold blast, acid lined cupola melting 52 tons per hour with an exhaust gas volume of 40,000 SCFM and a coke rate of 9.3 to 1. The data are inconclusive since they are not complete, but they do show an increase in emissions resulting from oxygen enrichment. Information from other sources indicate that although total emissions are increased, the improvement in the melting rate with oxygen enrichment results in a slightly lower emission rate per ton of metal melted. Additional testing is required to definitely establish the effect of oxygen enrichment on emission levels.

Several research programs are currently in progress to determine the effects of natural gas injection as a replacement for part of the coke charge. The results of one such program[5] are shown below.

Burner Height Inches	Coke Replaced with Gas Percent	Production Tons/Hour	Emissions Pounds/Ton
-	0%	14.8	67.8
50	30	20.1	57.1
50	40	20.3	58.5

The tests were run on a 90-inch diameter, cold blast cupola lined to 72-inch diameter, using a 4,000-pound metallic charge, 600-pound coke charge and 130 pounds of limestone. During the tests, the blast air was kept constant at 8,000 CFM, even though coke was replaced by natural gas on equivalent BTU content basis. The combustion air for the gas was provided stoichiometrically at a 10 to 1 ratio. The data show decreases in stack emissions of 15.75% for a 30% reduction in coke charged, and 13.7% for a 40% reduction in coke charged.

The emission rate of 67.8 pounds per ton reported for the control condition with no coke replacement is several times higher than shown in Exhibit VI-12 for a specific blast rate of 272 CFM/SF. Two special conditions, one inherent in the test program and the other a factor of weather conditions, could account for the discrepancy.

First, in the test program, the blast air was held constant at 8,000 CFM although the coke charge was decreased by as much as 40%. This quantity of air was further increased 36.5% by the natural gas and combustion air for replacement at 30% of the coke charge and 54.8% by the gas and air for the 40% replacement. It is reasonable to expect this increase in gas volume to augment entrainment of sand and small coke particles thereby increasing emission rates. Second, in answer to a query regarding the unusually high reported emissions,[6] the author reported that the tests were performed at a time when the scrapyard was wet and muddy resulting in the probability of significant amounts of soil adhering to the scrap charge, thereby adding to the stack emissions.

Although the emissions appear to be excessive, the data can be accepted as demonstrating the relative effect of the injection of natural gas on emissions levels.

The injection of other hydrocarbon fuels including coal and fuel oil has been reported in the literature. Less importance is attached to these efforts than the injection of natural gas, and no data pertaining to the effect of these fuels on emissions have been reported.

Discussion of Results

(a) Introduction

The effect of a number of variables on the type and quantity of cupola emissions has been evaluated by the use of a variety of analytical techniques. These variables include the following:

Cupola Design Variables

Lining - acid, basic, or unlined.

Blast Temperature - cold, warm or hot.

Blast Heating - external or recuperative.

Charging - side or top charge.

Gas Take-Off - below charge, above charge, top of stack

Afterburner - with afterburner or without afterburner

Charge Door - open or closed.

Fuel Injection - with or without fuel injection.

Oxygen Enrichment - with or without oxygen enrichment.

Cupola Operating Variables

Specific Melting Rate

Specific Blast Rate

Metal to Coke Rate

Blast Air Temperature

The analyses demonstrate that some of these variables have strong and quantifiable effects and others have statistically insignificant effects on emission devices. Six of the variables evaluated show evidence of the existence of relationships but lack of data prevents determination of the degree of correlation. Finally, for two variables, no proof of correlation can be found, although logic demands that a causal relationship exist.

(b) Variables with Proven Effect on Emissions

The established correlation between emission quantities and coke rate suggests that any operating procedure resulting in changing the coke rate will affect the quantity of particulate emissions. This includes heating of the blast air and oxygen enrichment or fuel injection with an attendant decrease in the coke requirement. The analysis for unlined cupolas calculated the effect of coke ratio and specific blast rate on emission quantities as $E = 57 - 6.6\ C + 0.1\ B$. If only the coke rate is considered, the relationship is E = 106.4 - 8.6 C. The index for the latter is lower than when both variables are considered jointly, but the equation can be used to approximate the single effect of coke rate on the emissions level. This effect for unlined cupolas is to decrease emissions by 8.6 pounds per ton of melt for each unit increase in the metal to coke ratio.

It is not possible to state the exact effect of oxygen enrichment in conjunction with changes in the coke rate because of limited data. It appears probable that the potential beneficial effect of the increase in coke rate permissible with four percent enrichment will be partially offset by an increase of very small, difficult to collect metallic oxides, resulting from increased oxidation in the melting zone.

The injection of natural gas with combustion air provided at a 10 to 1 ratio does not alter the oxidizing atmosphere in the melting zone. It would therefore be expected that emission rates with gas injection would approximate the results of the regression analysis as the coke charge is decreased, for a constant blast air to coke ratio.

The decrease of coke in the charge, while beneficial from the standpoint of emissions rates and overall melting cost, presents some metallurgical problems that must not be overlooked. The coke in addition to providing heat for melting also serves as a source of carbon often required to meet the desired analysis. This need is minor when the metallic charge consists primarily of foundry returns, cast iron scrap, and pig iron. In recent years, the increasing cost of pig iron has resulted in a shift away from this material toward steel scrap with drastically lower carbon content. This kind of charge requires a compensating carbon source such as graphite or the substitution of Cabot coke or Carbo-coke for the standard coke. No data are available to show the effect of these materials on emission levels.

The second major factor bearing a strong relation to emission levels is specific blast rate. Exhibit VI-11 shows that the specific blast rate varies over a range from 194 to 462 cubic feet per minute, per square foot of furnace area. Maximum blast rate is determined by the capacity of the blower and its motor. Rates below the maximum can be adjusted to suit the hot metal requirements since a decrease in airflow slows the coke combustion rate and the melting rate. Conversely, an increase in blast rate increases the temperature in the melting zone and the melting rate. The higher melting zone temperature will tend to increase vaporization resulting in greater amounts of metallic oxides, and the increase in airflow rate will increase its entrainment capability.

Specific blast rate gives no indication of the maximum rate of gas flow in the cupola, which is strongly affected by channeling within the burden. However, it is reasonable to expect that as the blast rate increases, the maximum potential gas flow rate will be directly affected, increasing the capability for entrainment of particulate matter.

(c) Cupola Design Variables

The analyses show that cupola emissions rates are not significantly affected by design factors of the furnaces within the parameters established by current United States design practices. These factors include the method of blast heating, top or side charging, charging door size and whether or not the opening is closed or open, the location of the gas take-off above or below the door, or an open stack permitting the gases to escape out the top. In addition, no significant effect on emissions rates was found for specific melting rates.

(d) Variables with Probable Effect on Emissions

Quantitative determination of correlation has not been possible from the available data for six factors showing probable effect on emissions levels. Results of test programs have been presented for oxygen enrichment and fuel injection, but additional data are required for quantifying the effects of these practices. Comparison of emission data from cupolas with charges including briquettes, or not including briquettes, shows that with other factors being equal, the use of briquettes results in larger emissions rates. Examination of emissions from acid brick lined cupolas shows lower average levels than do unlined cupolas but it is not established whether this condition results from the acid lining itself or the fact that coke rates are generally higher for lined cupolas.

A condition difficult to assign quantitative values to is the degree of degradation of coke and limestone when these materials are charged. Care in handling, degree of weathering, and efficacy of screening, when done at all, are all factors determining the quantity of breeze and dust charged into the cupola. There is general agreement that a direct relationship exists between the quantity of fine particles of these materials in the charge and cupola emissions. Only visual observation of stack plumes bears out the supposition, since no test data are available for positive verification.

A final variable with a strong indication of a causal relationship perhaps requires no proof of existence--that of the presence in cupola emissions of nonferrous oxides resulting from charge contamination. The quantities of oxides of zinc, lead, tin, copper, manganese, and the like can only derive from contaminants or alloying materials in the metallic scrap charge.

Even though scrap is purchased to specification, and the analysis is quoted by the dealer, it is possible that significant quantities of undesirable alloys or contaminants can be included in a shipment. In many cases, the existence and quantity of these materials can be determined only by an analysis of the cupola emissions, slag, and iron.

It would pose an almost impossible probelm to obtain a completely representative sample of scrap charge to determine a relationship of composition of input to that of the collected particulate matter. There are strong indications that inclusion of burned-in sand on foundry returns and dirt from the scrapyard results in increased SiO_2 concentrations in the emission. Here again the collection of data is extremely difficult--both the determination of the quantity of sand in the charge and the distribution of the sand in the particulate emissions and the slag. A similar indication of probable correlation, without sufficient data to establish an index of correlation, exists for the scrap metal thickness and degree of surface corrosion with iron oxide concentration in cupola emissions. The problem again relates to the difficulty of measuring corrosion and determining a reasonably accurate figure for surface area per unit weight of the metallic charge. Exhibit VI-14 shows the approximate surface area per ton and pounds of rust per ton for various ferrous scrap materials. An additional uncertainty exists in the amount of iron oxide, if any, converted to elemental iron in the reducing zone and melted, or being trapped in the slag.

(e) Variables with Expected Effect on Emissions

Two variables expected to show large indices of correlation with emissions levels surprisingly did not. Blast temperature shows in Exhibit VI-10 an expectedly high correlation of 0.874 with coke rate, indicating that the percentage of coke in the charge is usually decreased when the blast temperature is increased. Unpredictably, however, neither the coke rate with an index of 0.223 nor the blast temperature with an index of 0.294 correlated strongly with emissions levels. For unlined cupolas, practically no correlation exists between blast rate and any of the independent variables or the emissions level. No justification for this situation can be established.

No decrease in emissions clearly attributable to the use of afterburners was recognized by the analyses. A properly designed and installed system of afterburners will, in addition to burning carbon monoxide to carbon dioxide, reduce combustibles to ash, provided sufficient oxygen is available and the residence time is long enough for complete combustion. The unexpected lack of correlation between the use of afterburners and emissions level can only be explained by one or more of the following:

1. Afterburner not large enough or improperly installed.
2. Afterburner not operating at time of reported tests.
3. Insufficient retention time.
4. Insufficient oxygen.
5. No combustibles in stack.

The last two items are highly improbable, but any or all of the other alternatives are possible.

(f) Conclusion

The lack of correlation between standard furnace design factors and emissions levels requires that the explanation for the wide variance in type and quantity of emissions lies with cupola operating factors. This is borne out by the fact that all variables proven to affect emissions levels, or indicating a probability of affecting emissions levels, relate more to the operation of the cupola than to its design. These operating factors can be easily divided into two quite distinct groupings with some cross effects from one group to the other.

The first group consists of variables related directly to cupola operation, including specific blast rate, blast temperature, type of lining, and operating variables of the afterburner. The afterburner itself is an emission control device but adjustment of gas and combustion air is considered here as a variable for the melting system. These variables are relatively inflexible and are determined by required, or desired, operating characteristics.

The second group of variables concerns the quantity and quality of charge materials. These include coke rate, oxygen, natural gas, coke and limestone dust, briquettes often containing oil or cementitious materials, and contaminants or alloying materials in the metallic charge. These factors are highly variable, often from minute to minute, and are more controllable.

Insufficient data prohibit the quantitive evaluation of the total effect of all variables in the first group compared to all variables in the second group. The data suggest, however, that the type and quantity of cupola emissions are affected more by the quantity and quality of charge materials. Certainly little or no limestone dust, coke particles, or oil vapor and other combustibles will appear in the emission unless these materials are charged into the cupola. Similar statements can be made for zinc, lead, aluminum, chromium, cadmium, copper, silicon and other oxides, particularly when their formation is abetted by the injection of oxygen, or high blast rates.

Certain relationships expected to be identified by the analyses were not discovered. Blast air temperature, with a demonstrable effect on coke rate, was expected to show a secondary effect on the emissions level. The use of afterburners in the cupola stack has been shown to aid in the incineration of combustibles, the result of which would be to lower the emission levels to at least a noticeable degree. The fact that these relationships were not identified might be attributed to two factors possibly affecting all the analyses: the quantity and quality of the test data.

The limited availability of data has been documented, as well as the reasons for the short supply. The variable quality of the information is due first to the lack of understanding by foundry operators of the accuracy required of data for analytical purposes, and second to the several stack testing techniques in use by different testing laboratories. Where possible, questionable data were confirmed, and if verification was not possible, the data were discarded. The greater problem is in the results of stack sampling tests.

Stack testing is not an exact science at this time and no single technique has been accepted by the industry. Methods and equipment used to obtain the data listed in the foundry data bank have been discussed earlier. Repeatability of results is difficult with any given technique by a single testing firm, even for a stable emissions producing system. With relatively unstable conditions in cupola furnaces, and the generally poor working conditions existing at the top of cupola stacks, variation in results would be expected. With this situation further compounded by the use of different techniques, equipment, and testing companies to obtain data for comparison and analysis, the confidence level of the data must suffer, despite the high degree of professionalism of the laboratories performing the tests. As a result of this condition, all data used in the analyses have undergone critical evaluation before acceptance. Even with this method of reviewing data, it is believed that identification of less strong relationships might be missed in the evaluative processes, and that only strong relationships will be recognized.

The problem of comparing stack test results obtained with different test procedures is expected to end with industry acceptance of the recently published "Recommended Practice for Testing Particulate Emissions from Iron Foundry Cupolas." The procedure was developed by a joint industry committee sponsored by the American Foundrymen's Society and the Gray and Ductile Iron Founders' Society, Inc. The committee investigated the theorectical and practical aspects of stack testing and held discussions with representatives of the various testing laboratories to gain additional insight before writing the procedure.

The recommended practice, included in Appendix E, is based upon the American Society of Mechanical Engineers Performance Test Code 27-1957, Determining Dust Concentration in a Gas Stream with certain modifications to satisfy the special conditions existing in the iron melting cupola installation. Three special conditions are identified as follows and recommended test procedures are established for each:

1. Sampling raw particulate emissions in the cupola stack where gas flow fluctuates, flow rate is low, gas temperature is high, and dust loading is extremely uneven.

2. Sampling raw particulates emissions in the inlet duct to the dust collector where velocities and loadings are more uniform, flow rate is greater, temperatures are more moderate, and humidity is high.

3. Sampling cleaned gases at the dust collector outlet where velocities and flow rates are nearly uniform, and dust loadings are low.

EVALUATION OF EMISSIONS FROM OTHER SOURCES

Although the cupola has been considered to be the principal source of iron foundry emissions which are difficult or costly to control, there are other areas in the foundry which also produce these types of emissions. The earlier discussions in this report covered the equipment and operations in the iron foundry which produce emissions. Some of these have been adequately and economically controlled with existing designs of equipment, while others have proven to present problems which have not yet been completely solved. In Exhibit V-1, these emissions sources are classified according to the ease and economy with which they can be controlled.

The ease and cost of controllability can generally be related to two broad aspects: the problems which relate to capturing the emissions with a minimum of infiltrated air and the problems of adequately removing the fine particles and gases from the capture medium before their release to the atmosphere. In general, those operations which in many foundries take place in open, nonconcentrated, nonstationary locations are difficult to control although, in many cases, the actual costs of control may not be high once the emissions are captured. These operations take place in the scrapyard, mold pouring area, and the shakeout area.

The other areas which involve difficulty of capture and high cost of control equipment include arc melting, magnesium treatment to produce ductile iron and coremaking. The discussion in this section concentrates on these areas.

A general problem encountered in analyzing these areas, other than the cupola, is that relatively little quantitative information is available regarding the quantity and nature of emissions generated. As a result, much of the data in the following paragraphs were developed by analytical methods and by adaptation from similar operations in other industries, rather than from actual field information.

Electric Arc Melting and Holding

The number of electric arc melting installations in iron foundries is relatively small, with less than 50 known to exist in 1959, and approximately 200 in 1969. This is a small factor when compared with the cupola. However, the trend toward electric melting, both arc and induction, is increasing rapidly, and the electric arc furnace will most certainly be a growing factor in the iron foundry.

Because of its greater importance in the melting of steel, much attention has been given to the emissions problems from arc melting in the steel industry and in the steel foundry. Practically all of the emissions data which have been gathered have been in these industries as distinguished from the iron foundry industry. Steel production and melting in electric arc furnaces can be classified into two broad groups. The first involves basic melting practice in which refining as well as melting is performed and in which one or two slags are formed to eliminate impurities. The second involves acid melting practice, in which almost no refining is done and in which only a minimal slag is produced.

Acid steel melting is very similar to iron melting in the arc furnace, with the principal difference being the common use of oxygen injected into the molten steel as a means of rapid reduction of carbon content, while iron is melted without the use of oxygen and, in fact, usually must have the carbon content raised by carbonaceous additions. With the exception of the gases evolved during oxygen lancing, the emissions evolved in both types of acid melting are similar.

The emissions from iron melting in the arc furnace come from two principal sources--the burning or vaporization of combustible materials which may be in the charged raw materials, and the burning of the electrodes and some of the charge metallics during meltdown. In both cases, the greatest evolution of gases occurs during the early part of the cycle, when meltdown takes place and when the electric power consumption is highest. Although the type and quantity of emissions from combustion of impurities in the charged materials is highly variable depending on the nature and cleanliness of these materials, the gases produced from combustion of the electrodes are a known and comparatively constant and calculable source of emissions. Approximately 9-11 pounds of electrodes are consumed per ton of iron melted, producing approximately 30 pounds of CO and CO_2 gases, plus 150 pounds of N_2 which comes from the air induced into the furnace. Additionally, a small quantity of the metallics, principally iron, is oxidized and emitted as oxide fumes.

Four of the iron foundries visited during the course of this study were electric arc melting installations, all having fabric filter collectors for emission control. Samples from the collectors of three of these were anlayzed for particle size distribution and for chemical analysis. The results of these tests, together with reported emission rates per ton of iron melted, are given in Exhibits VI-15 and VI-16. Data on the furnace sizes and dust collector system size are also given.

Although the collected data are insufficient for the type of analysis which was conducted for the cupola, they can be combined with other data for acid steel melting as well as iron melting to form certain general conclusions. Exhibit VI-16 gives these additional results for a variety of installations ranging from 2- to 25-ton capacities, all melting in acid furnaces without use of oxygen. The wide range of emissions rates, from 4 to 40 pounds per ton of charge metal, and the lack of correlation with furnace size suggest that the rate at which emissions are produced is relatively independent of these factors. A slight trend appears to exist toward a relationship between the rapidity with which melting occurs and the rate of emissions produced, indicating that a high concentration of melting power to produce short melt cycles will also produce higher emissions. This conclusion is further verified by the graph in Exhibit VI-17, in which the concentration of heavy rate of emissions is in the early or meltdown part of the cycle. The less time devoted to the holding or refining period, the more concentrated the emission rate will be during the cycle.

The particle size of emissions produced is given in the analysis of collected material from three foundries in Exhibit VI-15. The fineness of a large portion of the emissions, with 50%-75% being under 5 microns in size, makes the collection problem more difficult, requiring the use of high efficiency collectors such as fabric filters, high energy wet scrubbers, or electrostatic precipitators.

The chemical analysis of the emissions is also of interest. As expected, the emissions consist almost entirely of oxides of the various metallics charged, and the furnace refractories and fluxing materials which were used. Iron oxide forms the major constitutent. Other metallic oxides present will obviously vary according to the types of charge materials used.

The conclusion drawn from the foregoing analysis is that the nature and cleanliness of the charged materials are the most important variables in determining the quantity and nature of the emissions produced. Rapidity of meltdown contributes to a lesser degree, and other factors of design and operation are of relatively small importance in emissions production during iron melting in the electric arc furnace.

Magnesium Treatment for Producing Ductile Iron

The practice of producing ductile iron by ladle inoculation of molten iron with magnesium, or other light metals which produce similar effects, is only about 20 years old, but it has rapidly become an important factor in the iron foundry, now representing about 10% of iron tonnage cast. Despite this, there has been relatively little information gathered regarding the nature and quantity of emissions produced during this practice. The treatment agent is commonly a form of magnesium which can be introduced into the molten iron to produce the desired effect. Exhibit VI-18 illustrates the various methods by which this can be accomplished.

The reaction produced during the magnesium treatement process is a violent one, but of short duration, although the degree of the violence varies with the form and method of introduction of the magnesium. Because of this, only a relatively low percentage of the magnesium which is introduced is actually involved in the reactions which produce ductile iron, with the remainder being vaporized and expelled as a fume. The actual yields vary from as low as 15% to as high as 75%, depending on the treatment agent used and the rapidity with which it is added to the iron bath. The yield factor which is most generally accepted is about 30% to 35%.

Although several ductile iron foundries have installed emissions control systems on the treatment stations, none has attempted to measure the quantity of emissions per ton of iron treated, or to analyze the emissions to determine the particle size distribution or the chemical composition. The analysis, therefore, is based on an analysis of the known reactions which occur, and the normal yields which are expected during the process.

Magnesium is the principal agent resulting in emissions, since the alloying materials which are used as carriers of the magnesium either dissolve in the iron or oxidize to form slag. A major exception to this is the use of magnesium impregnated coke which evolves CO and CO_2 gas as well as MgO fume. The boiling point of magnesium is about 2,025° F, which is well below the temperature of molten iron and accounts for the violence of the reaction which takes place. The magnesium in the inoculant is used up in three ways:

1. Some magnesium will react with any sulfur present to form MgS, and become part of the slag. Although iron which is to be used for ductile iron production is generally pretreated with a basic material such as Na_2CO_3 or $CaCO_3$ to remove sulfur, there is usually about .02% to .03% of sulfur remaining. This will be effectively eliminated by the magnesium, using about 0.5 pounds of magnesium per ton of iron.

2. A small quantity of magnesium will dissolve in the iron, to the extent of about .04%. This amounts to about 0.8 pounds of magnesium per ton of iron.

3. The remaining magnesium will boil off, forming MgO upon contact with the air. The amount of magnesium added will vary from 0.12% to 0.30% of the iron treated or from 2.4 to 6.0 pounds of magnesium per ton of iron. Deducting the 1.3 pounds of magnesium which was consumed by sulfur reaction or dissolved in the iron leaves from 1.1 to 4.7 pounds of magnesium per ton of iron treated to form MgO fume. This will result in about 2 to 8 pounds of MgO fume generated per ton of iron treated.

The fume from the magnesium treatment process will be largely MgO, with this material accounting for from 60% to 80% of the total, depending on the form in which the magnesium was introduced and the violence of the reaction. The more violent reactions, particularly when silicon-magnesium alloys are used, will also produce SiO_2 particles in the emissions. Iron oxide, as Fe_2O_3, will also be found in the emissions and will constitute the second most important material present, after MgO.

Particle size of the emissions will be fine for the MgO and Fe_2O_3 portions, with the silica and alumina particles generally of larger size. These particles are under one micron in size and are difficult to collect, requiring the use of fabric filters or high energy wet scrubbers.

Exhibit VI-19 gives the reported results from the magnesium treatment station of a large gray and ductile iron foundry. This station was used for ductile iron treatment, desulfurization and ferrosilicon inoculation, which explains the presence of such elements as sulfur and calcium in the catch. The amount of magnesium in the inoculant was 2.25 pounds per ton of iron treated. At a yield of 35%, this resulted in 1.45 pounds vaporized, giving 2.4 pounds per ton of MgO. This amounts to 73% of the emissions actually captured.

Mold Pouring and Cooling

Molding sands consists of silica, zircon, olivine, chamotte, and occasionally other mineral grains bonded with clay, bentonite, portland cement, plaster of paris, petroleum residues and bitumens. Additives are often added as cushioning materials, with such materials as sea coal, pitch, wood flour, silica flour, perlite, ground cereal hulls and chemicals in common use. Although these binders and additives improve the strength, molding properties, and casting properties of sand, they also contain amounts of combustible materials that form gas which evolves during the pouring and cooling of molds.

Green molding sands, which are most commonly used in iron foundries, may contain the additives shown below.

Additive	Amount by Weight
Wood flour	0.5%- 2.0%
Sea coal	2.5%- 8.0%
Cereal binder	0.5%- 1.0%
Silica flour	0.0%-15.0%

The effect of molten metal during pouring is to vaporize the volatile materials and the water contained in the molding sand adjacent to the mold cavity. Although this effect decreases rapidly as the distance from the cavity increases, the gas formed is forced through the mold vents and is expelled into the surrounding atmosphere. The nature of this gas is illustrated in Exhibit VI-20. While these data refer to molding sand formulations for steel castings, they are also representative of gas formation in iron sand. The combustible portions are relatively high, consisting of from about 3% for dried molds to as high as 81% for molds with a high percent of cereal and bentonite. The H_2 in the combustibles comes from decomposition of water vapor, while the CO comes from combustion of organic materials.

The volume of gas formed is illustrated in Exhibits VI-21 and VI-22, for various mold materials. Gas evolved ranges from 74.4 to as high as 824 cubic feet per cubic foot of sand at 1,800° F. Only a small portion of the sand adjacent to the sand-metal interface approaches this temperature and gas formation drops off rapidly as the distance from the interface increases. Although relatively small amounts of particulates are involved, the potential toxicity of the unburned combustibles makes collection an important factor. The high temperatures associated with pouring often result in burning of gas as it leaves the molds. This afterburning is desirable to completely convert the combustibles to CO_2 and water vapor and to eliminate explosion and toxicity hazards, particularly if the mold contains oil sand cores.

Coremaking

Emissions resulting from coremaking operations are generally in the form of vapor, dust and gas, the type and amount depending on the nature of the core mix and the coremaking process. The core mix is typically comprised of silica sand, binder and moisture. The binders used in coremaking include linseed oil, core oil, wheat flour, sulphite, pitch, oiless binders, resins, silica flour, fire clay, wood flour, iron oxide, bentonite, and silica sand.

Core binders that generate a considerable volume of gas on pouring of the mold are undesirable. A typical core mix for malleable iron castings might be as follows:

Sand	Cereal	Moisture	Oil	Binder
92%-98	.75%-1.25%	0%-5%	0%-1%	0%-.5%

Core mixes for gray iron castings vary greatly according to the general size of the casting and the specific application for the part. The rate of gas volume generated in a core during the pouring process is largely a function of baking time and temperature. Exhibit VI-23 illustrates the effect of baking time on the volume of gas generated at various baking temperatures. A review of the curves quickly points out that the gas content is reduced by baking at higher temperatures.

Resin binders of the type normally used in shell cores present varying degrees of hazards due to the toxicity of the decomposition products. Dermatitis is the principal effect caused by an excess of free phenol, formaldehyde, hexamethylenetetramine or alcohol. The extent of the hazard depends upon the specific agent and the tolerance level for that agent. Phenol, for example, can cause dermatitis and do organic damage to the body at levels exceeding five parts per million. Formaldehyde is a nuisance at levels exceeding five parts per million. Hexamethylenetetramine can cause skin irritations with direct contact.

Other toxic and irritating materials include furfuryl alcohol, ethyl alcohol, methyl alcohol, urea, carbon monoxide and silica dust. These can be released during shell operations. Each has varying minimum levels of concentration before its toxicity or irritation are critical or a nuisance. Ventilation becomes the important factor in minimizing these hazards. The sand to oil ratio has a bearing on the volume of gas generated in a core during pouring. The effect of sand to oil ratio on the amount of core gas given off during pouring is illustrated in Exhibit VI-24. The relative amounts of gas produced by various core binders is given in the following table.

Core Binder	Cubic Centimeter Gas per Gram
Linseed	380 - 450
Petroleum	350 - 410
Urea resins	300 - 600
Cereal	550 - 660

REFERENCES

1. Foundry Air Pollution Control Manual, American Foundrymen's Society, 1967.

2. Dust Separating Apparatus, American Society of Mechanical Engineers, PTC 21-1941.

3. "Influence of Melting Method and Charge Composition on Cupola Effluent," Mark M. S. Chi and F. Ekman, paper presented before 1970 AFS Casting Congress and Exposition, Cleveland, Ohio.

4. Kupolofenentstaubung, G. Engels and E. Weber, Giesserie-verlag G.m.b.H., Dusseldorf, translated by P. S. Cowen, Gray and Ductile Iron Founders' Society, Cleveland, Ohio.

5. "Gas Injection Lowers Cupola Melting Costs, Increases Melting Rates," J. A. Davis, et al, Foundry, June, 1969, pp. 66-73.

6. "Readers Comment. Letter from Institut fur Giessereitechnik," Dusseldorf, Germany, Foundry, December, 1969, p. 48.

VII - TECHNICAL ANALYSIS OF EMISSION CONTROL TECHNOLOGY

ANALYSIS OF EMISSION CONTROL TECHNIQUES

Over the years, increasing attention to foundry and other industry sources of emissions has prompted development of many types of equipment for control of the emissions from these sources. As the significance, complexity and scope of the problem grew, new designs were introduced or existing ones modified.

The problems arising from each type of foundry emissions and the equipment best suited for control vary with the nature of the specific problem.[1] These systems, which include dry centrifugals, wet collectors, fabric filters and electrostatic precipitators, vary widely in design, capacities, capabilities, cost and application.

Dry Centrifugal Collectors

(a) Historical Background

Low pressure drop centrifugal collectors were first developed in about 1880 to remove dust from the secondary circuit of dust louvres. Higher pressure loss centrifugal collectors were introduced in the 1920's in Europe. At about this time, small diameter cyclones connected in parallel were being used in the United States. Although first applied to boiler fly ash processing, they were to become the usual application for grinding and chipping operations. Design improvements increasing the collection efficiency were made in the 1940's and early 1950's making it possible to apply centrifugal collectors to cupolas.

(b) General Characteristics of Equipment

Dry centrifugal collectors are essentially low energy units operating on the principle of mass force action on individual dust particles. Gravity, inertia, and centrifugal force act to separate the dust particles from an airstream. It is important that this type of collector operate within design limitations to maintain proper efficiencies. If the gas flow drops below normal, inertia or centrifugal forces are reduced and collection efficiences are lowered. Excess moisture in the gas stream also results in reduced effectiveness by clogging the system.

Physical characteristic of the dust is an important factor in the application of centrifugal collectors. Particle size, shape and density determine, in large part, the ability of these collectors to function properly. The collection efficiency required for a particular application is also a major factor in selection of a centrifugal collector. High efficiency requirements may preclude the use of this type of collector with its limited effectiveness.[1]

(c) Description of Specific Types

Four basic types of dry centrifugal collectors currently in use are: cyclone, high efficiency cyclone, high efficiency centrifugal and dynamic precipitator.

1. Cyclone - This unit type is essentially a conical chamber with a dirty air inlet on the periphery, a clean air exhaust at the top, and a dust removal opening at the bottom of the cone. In a common cyclone design, contaminated gases are tangentially led into the unit so that a rotational gas flow is produced. The dust particles travel towards the outside and bottom of the chamber under the influence of centrifugal force. The particulate matter enters a collection bin or hopper and settles, while the cleaned gases, which also traveled to the bottom of the cone during the centrifugal action, leave the cyclone through a pipe or tube located in the middle of the system.[3]

The dust collection efficiency of cyclones depends on the pressure drop which increases with the inlet velocity of the dust gas mixture in the collector. The larger the pressure drop, the smaller the limiting dust grain size, and the higher the collection efficiency. As gas velocity increases, collection efficiency will increase rapidly. However, at a certain point, a further increase in gas velocity will not raise efficiency by any noticeable amount. Collection efficiency of cyclones also depends on other factors such as the quantity and nature of the dust, their surface properties, electrical charge and moisture content.

Electrical charge is important with regard to submicron particles. If emissions are charged similarly, they tend to repel each other with the result that collection efficiency drops.

Conversely, agglomeration takes place and efficiency increases when positively and negatively charged particles are present.

In addition to the dirty gases being tangentially led into the cyclone collector, there are other input methods used. Inlet spiral or axial and radial guide vanes, on the inlet side of the dust collector, can also be utilized.[2] An example of a cyclone is shown in Exhibit VII-1.

2. High Efficiency Cyclone - This type of unit is similar to regular cyclones in design and operation. Differences exist in the diameter and shape of the two units. High efficiency cyclones usually have a smaller diameter chamber and a longer cone than regular cyclones.

Pertaining to the collection operation of these units, higher efficiency can be obtained in comparison to regular cyclones. This is achieved by the increased velocity that exists with high efficiency cyclone units and greater centrifugal force resulting from the smaller diameter. Energy requirements of high efficiency cyclones are somewhat greater than regular cyclones. Pressure drop is in the 3- to 6-inch water gauge range with high efficiency units whereas regular cyclones obtain approximately a 1.5- to 3-inch level. With the greater energy requirements of a high efficiency unit, a more powerful fan and drive are needed.

With these units, dust discharge must be continuous to a dust storage bin that is often equipped with an air lock or flap gate discharge device. Collected dust must not be stored in the cone bottom since reentrainment and loss of efficiency would result. High efficiency units generally operate on suction but can also operate on the pressure side of the fan.

Maintenance of these units requires periodic inspection of interior surfaces for wear. The discharge device should also be examined for proper operation.[4]

3. High Efficiency Centrifugal - High efficiency centrifugal collectors consist of a series of small cyclone-type units in a single housing. Different designs of this unit type are available. One type utilizes swirl rings that help produce a cyclone motion in the airstream. The cleaned air is exhausted out the center section of the cyclone and the dust settles into a storage hopper. Another type utilizes multiple tubes and a secondary air circuit to achieve a higher collection of small particulate matter. In the operation of this system, dirty air enters through an inlet that has a slot for maintaining a uniform distribution of the air. The incoming air moves tangentially to provide the cyclonic action to hurl the particles to the outer periphery of the tube. The dust and a portion of the primary air are bled off. The clean air passes out through the end of the tube into a main duct. Larger dust particles then fall into a hopper and the remaining dust and secondary air are drawn through another set of tubes. The air also enters tangentially in these tubes and the remaining dust particles move outward and exit into a hopper. The clean air passes back through the center of the tubes and reenters on the inlet side of the unit. If this type of unit is used on cupolas, other equipment such as cupola caps, pressure relief vents, gas burners, cooling towers and high temperature ductwork is required.

Due to the high internal velocity of the air, various component parts may tend to wear. This requires inspection of all tubes, wall surfaces and hoppers to assure proper functioning.[4] Pressure drops are in the range of four to six inches water column, and collection efficiencies somewhat higher than for high efficiency cyclones. The small dust outlet size can be plugged more readily and poor distribution within the collector can cause short-circuiting within the dust hopper which will reduce collection efficiency.[5]

An example of a high efficiency centrifugal unit is illustrated in Exhibit VII-2.

4. Dynamic Precipitator - This dry centrifugal collector consists of three main components: an impeller, housing, and a dust chamber. The impeller's purpose is to move the air, guide the airflow and force the dust particles to the periphery by centrifugal force.

The housing has two compartments--one for cleaned air which comes from the impeller and is projected out the discharge, and the other for dirty air which is discharged from the impeller. This dirty air goes into a hopper after which a decrease in velocity takes place that allows the particles to settle. The cleaned air is then returned into the outer compartment. Collected material is usually emptied from hoppers and disposed of in the dry state.

There are modifications which can be made to the system described in the previous paragraph. If larger particles or heavier concentrations exist, a skimmer may be used. The operation of a skimmer is similar to that of a low energy mechanical collector. In addition, aftercleaners are sometimes used if the dust is nontoxic. Aftercleaners assist in removing small particulate matter and also allow filtered air to be returned to the plant. Maintenance of the system is required for such areas as internal surfaces and bearings.[4]

An example of a dynamic precipitator is shown in Exhibit VII-3.

(d) Advantages of Dry Centrifugal Collectors

Certain dry centrifugal designs such as cyclones and high efficiency cyclones are relatively simple in operation and do not require a large investment cost.[2]

Common cyclones are simple to maintain although inspection of portions of the system are required. Furthermore, dynamic precipitator installations can be modified in the future with the addition of skimmers or aftercleaners. This permits a more flexible collection operation.[4]

Finally, protective devices can be installed on some designs of these systems to enable gas bypass in case of failures.[6]

(e) Disadvantages of Dry Centrifugal Collectors

These systems are subject to abrasion and therefore require periodic inspection to operate properly. Common cyclones require inspection usually to a lesser degree than other dry mechanical systems because of their larger scale application to coarse particle problems.

If dry centrifugal collector systems are not operated within their airflow design specifications, collection efficiencies achieved will be lower than what the system is capable of capturing. Furthermore, compared to the other three basic emission control systems, dry centrigual collectors achieve the lowest collection efficiency on fine and medium-sized particle dust.

With dry centrifugal collectors, a dry dust disposal problem exists depending on the type of refuse handling equipment utilized by the particular foundry. Dry dust is difficult to wet, and disposal often results in secondary pollution.

Certain systems such as high efficiency centrifugal units, when installed on cupolas, require additional equipment for dust handling and disposal which adds to investment requirements.[1]

(f) Limitations of Dry Centrifugal Collectors

Dry centrifugal collectors have the greatest limitation of the four emission control systems under consideration regarding particle size that can be captured. The smallest particle dynamic precipitators and high efficiency centrigual units can effectively collect is approximately 10 microns in size. Common cyclones have a greater limitation in that the smallest particle size they effectively collect is in the 20-40 micron range.[4]

These limitations prevent their effective application to a number of foundry processes. Dry centrifugal collectors are not applied to electric melting processes, mold cooling, pouring, core and paint ovens or oil burn-off furnaces. Finally, these collection systems are normally not capable of operating at temperatures above 750° F unless special heat resisting alloys are employed.[5]

Wet Collectors

(a) Historical Background

Wet collectors have been applied in foundries to control emissions since the late 1930's. Low energy units were first introduced, including the wet cap which became popular during World War II.

As residential areas developed closer to foundry operations, nuisance complaints from dust settlements increased. Conventional medium energy wet scrubbers such as centrifugal units were introduced in the 1950's to help solve this problem.

Later, the public demand for removal of finer particles from cupolas encouraged the application of high energy scrubbers such as venturis. With the advent of the venturi scrubber, a substantial increase in wet cleaning efficiency was introduced.[5]

(b) General Characteristics of Equipment

Wet collectors all utilize water, or a water solution, as a means of capturing and removing dust particles from an airstream. In general, three basic principles are involved:

1. Saturation of the Airstream - A wet collector must first saturate the airstream to retain dust particles

captured. If the water used for collection is allowed to evaporate, the dust particles will be released.

2. Wetting - Wetting of dust particles is necessary, since the particles cannot be captured unless their surface is wet.

3. Separation - After thorough wetting and capture of the dust, the water droplets containing the dust particles are separated from the airstream.[7]

Wet collectors can safely handle high temperatures, high moisture content and fine clay bond particles without obstruction to air moving or particle collective functions. Furthermore, this type is most practical for foundries having an existing supply of low cost water and the ability to dispose of collected waste in slurry or sludge form. In fact, collector designs will be determined to a considerable extent by the foundry water supply and water clarification system being employed. Unit systems will incorporate self-contained water circulating systems with either integral or auxiliary settling tanks for dewatering and removing collected sludge.

For large production foundries, central sluicing systems are sometimes employed to eliminate multiple disposal points and in-plant haulage of the collected sludge. Collectors drain continuously to the sluicing system. Collected material is settled out in large settling tanks or tailing ponds with water usually recirculated after clarification.[5]

(c) Description of Specific Types

Seven specific types of wet collectors used are: static washer, dynamic precipitator, centrifugal, orifice, centrifugal spray, flooded bed and venturi.[1]

1. Static Washer - Static washers, the simplest form of wet collectors, are used where moderate to heavy concentration of dust particles and lower efficiencies are expected. This design usually consists of a shell or housing containing banks of water sprays, simple scrubber plates, additional sprays, and moisture separators. Spray towers or stacks equipped with water sprays fall in this classification. The lower section of the collector is cone-shaped to collect and drain the collected liquid. Additional equipment required for these collectors includes pumps and/or piping for circulation of water, a means of disposing of the collected sludge and fans in all cases except the wet cap which relies on natural draft. The basic principle for cleaning with a static washer is that the dirty gases come in direct contact with sheets or sprays of water which flow in the opposite direction of the gases.

The most common type of cupola static washer is a wet cap which is shown in Exhibit VII-4. Designed relatively simply, wet caps usually consist of one or more inverted cones surrounded by a collection trough. By directing a stream of water over one or more of the cones, placed above the top of the cupola, a water curtain is formed through which cupola gases must pass and by which heavier particles of dust are removed from the gas stream.[4]

Water in a wet cap operation can be applied in numerous ways: an open waterline can be centered above the apex of the cone flow by gravity; a spray nozzle can be mounted above the apex of the cone; sometimes clusters of the cone are arranged horizontally and vertically; a ring of nozzles may be used; water can be discharged from a hole in the cone apex and flow downward by gravity; a continuous plate is also used whereby water enters in sheets; with the cone hollow, water can be discharged from nozzles mounted at the periphery; and finally, a small receivable water distributing head is sometimes mounted above the main cone and water enters from an adjustable slot at the periphery of the small cone.[8]

2. Dynamic Precipitator - This type is used to collect light to heavy concentrations of fine particles such as found in shakeouts and other sand-handling applications. Essentially, the dynamic precipitator is a combined exhaust fan and collector. This design consists of a prepackaged unit made up of an inlet duct with a spray nozzle, a multi-bladed impeller and a special housing that separates the cleaned air from the dirty slurry.

The basic cleaning process consists of dirty gases entering the inlet duct where they are mixed with water. Specially designed blades then remove particles by capturing the dust on a moving film of water on the blade surfaces. The force of the moving wetted blades provides the energy to wet the particles, and the centrifugal force discharges and separates the collected dust in the form of a slurry while exhausting the cleaned air. An example of a wet dynamic precipitator is shown in Exhibit VII-5.

Dynamic precipitators must be periodically inspected to assure that the fan rotor and spray nozzles are not clogged.

The rotor must also be checked for wear and buildup on blades. This could cause an unbalanced operation and excessive loads on fan bearings.[4]

3. Centrifugal - Centrifugal wet collectors are used to remove dust from sand conditioning equipment, casting lines and cupolas. The two basic designs available in this category are the vane type and multiple tube type. The vane-type collector consists of a vertical cylindrical housing and one or more stationary vanes and impingement plates. The tube type utilizes a rectangular housing surrounding inlet collector tubes, a water eliminator section and a clean air section. Both types utilize simple water piping to produce a film of water on the surface of the vanes. Additional equipment includes pumps and/or piping for water circulation, a method of disposing of sludge and an exhaust fan.

With a vane-type centrifugal collector, dirty gases enter the bottom of the main housing at a tangent which provides the centrifugal force to impinge the larger particles against the lower section of a shell. The gases and smaller particles flow upward through vanes which produce a turbulent action. Dust is removed by coming in contact with the wetted impingement plates and water droplets. The gas then passes through a separator where the free moisture is removed. An example of a vane-type centrifugal collector is shown in Exhibit VII-6.

In the operation of the tube-type centrifugal, dust-laden gases are led in tangentially at the upper end of the collector and then move through multiple tube-type canals. Centrifugal force hurls the dust particles against the wetted peripheral surface of the unit. The slurry is then separated from the clean air by being forced down and out the bottom of the collector. The clean gases move parallel to the water stream towards the outlet at the lower end of the dust collector.[4] Exhibit VII-7 illustrates a tube-type wet centrifugal collector.

4. Orifice - This collector type is used in sand handling and cleaning processes. Orifice units are rectangular and employ one or more impeller orifices that are submerged in water. The clean air side of the main housing is equipped with baffle plates to separate entrained moisture. Orifice collectors utilize the principle of centrifugal force and the mixing action of dust-laden gases and water to achieve cleaning.

The first step of the cleaning cycle consists of contaminated air entering the collector horizontally after which it is violently pulled down through water. Fan suction continuously draws water and air up where it impinges against a plate and sprays off. This action causes great turbulence, which in turn wets the dust particles. The gases are then exhausted out the collector after which a drag conveyor continuously removes the settled sludge. An orifice-type unit is shown in Exhibit VII-8.

Water is continually reused and since a water curtain is produced by airflow, no pumps and nozzles are required. Furthermore, orifice collectors normally do not require extensive maintenance because the only moving device is an exhaust fan. In addition to fan maintenance, occasional inspection and cleaning of the impeller and moisture separator are also required.[4]

An important operating requirement of baffle-type orifice collectors is that the water level must be synchronized with the amount of air flowing through the unit if constant collection and reasonable pressure drop are to be maintained. Recent orifice designs automatically adjust operating water levels when the exhaust volume varies.[9]

5. Centrifugal Spray - This unit is used on a wide range of foundry applications from shakeouts to cupolas. The centrifugal spray collector consists of a cylindrical shell in which are mounted a pump, spray generator, and fan, all on a common shaft. A separator is mounted on the upper section of the shell.

Collection is achieved by combining high kinetic energy water droplets with the contaminated gas. Dirty gas enters the unit and is directed under a stationary impinger where heavy particles are impacted and carried off by liquid water. After this, the air is drawn up through a high velocity water spray, where impingement of the smaller dust particles takes place. The cleaned gases continue upward through a moisture separator and finally are exhausted from the unit. Exhibit VII-9 illustrates a centrifugal spray wet collector.

A variation of the design described above is a scrubbing unit consisting of a cone bottom housing and a pump spray generator device. This unit is usually coupled with other units such as separate exhausters, hot gas quenchers, moisture eliminators, etc. to make a cupola cleaning system. The cone bottom unit operates on the same principle as the cylindrical shell for the removal of airborne water which is handled by the moisture eliminators.

These units utilize much of their input horsepower to create a high energy water spray. This is different than other wet-type units which overcome static pressure drop across the collector.

Centrifugal units require periodic inspection and servicing of pumps, spray generator cage, bearings, the main shaft and drive motor.[4]

6. Flooded Bed - The two basic types of flooded bed collectors are marble bed and impingement baffle grid. Both designs have common characteristics and also some differences. Each employs a cylindrical shell with a cone-shaped bottom section, fixed blade moisture separators at the top of the shell and spray nozzles below the first stage of scrubbing. Furthermore, both types operate on the principle of direct contact of dirty gases with water spray in conjunction with venturi-designed induced turbulence. In a typical marble bed collector, gases enter the collector near the bottom and then turn upward into a water spray. These water sprays are used to wet the lower portion of the bed. This causes the larger dust particles to separate and drop down. The gases and water are then drawn up by an exhaust fan through a bed of glass or other type balls where smaller particles are captured by the restricted flow. The cleaned gases ascend further and move across moisture separators and then out the collector. The dust-laden slurry is drained down and into a sludge hopper. An example of a

marble bed collector is shown in Exhibit VII-10.

Efficiency of this unit can be increased by additional layers of balls. Spheres packed in contact with each other constitute a multiplicity of venturis to achieve this result.

The impingement baffle grid collector uses one to three grids which consist of a perforated plate and impingement plate above each perforation. An essential difference of the impingement baffle grid from the marble bed unit is in the water supply. Each scrubber section of the grid type has an individual water supply in addition to the water spray located in the cone section. Exhibit VII-11 shows a grid-type flooded bed collector.[4]

7. Venturi - This unit is usually applied where heavy concentration of both coarse and extremely fine particles exists and high efficiencies on submicron particles are desired. In a typical cupola system, hot gases move from the furnace to a quencher where they are cooled by a water spray. Here, the large particulate matter is removed. From the quencher, gases are directed to the venturi where they are accelerated to a high velocity and brought into contact with multiple jet streams of water. The water and gases are drawn through the constricted throat of the venturi at such a high velocity that the water atomizes into minute droplets and dust particles collide with the droplets and become wetted. This wetting occurs in the diffusion area downstream from the venturi throat. The dirty water is carried out the bottom and the gases pass through a moisture

separator, are cooled and then exit through a saturated gas stack. A high pressure exhaust fan, piping and electrical controls are part of the system. Exhibit VII-12 illustrates a venturi collector.

Venturi scrubbers achieve a high efficiency by virtue of a high pressure drop occurring across the venturi throat. Some venturis are designed with variable throats so that a more uniform pressure drop can be maintained with variable gas flow.

A variation of the venturi described above combines a marble flooded bed collector with a venturi section mounted underneath. Nearly all of this system is encompassed in one large chamber. In the operation of a flooded bed venturi, dirty gases enter the collector where they are met by a cooling water spray. The gases then turn upward into the venturi and the large particles drop out of the airstream into a cone section. Gases and fine particles pass across the venturi and the particles become wetted. The marble bed and moisture eliminator act to further clean the gases and remove water drops from the effluent.[4]

(d) Advantages of Wet Collectors

Wet collectors can be applied to a variety of foundry applications. Certain designs, such as wet caps, require a relatively low initial investment cost, limited space needs, no induced draft fan and are rather simple to maintain.[6]

Venturi scrubbers have good collection efficiencies down to particles of 0.1 or 0.2 microns in size but also have high energy requirements to achieve this cleaning capability.[4]

In addition, wet collectors are capable of handling hot gases, sticky dust and high moisture content. In some cases, disposal of sludge can be achieved if foundries have slurry pumps, settling ponds or tanks, drag chain sludge removal conveyors or other similar equipment.[1]

Finally, these system types are safer from fire hazards than fabric filter collector designs.[2]

(e) Disadvantages of Wet Collectors

One major disadvantage is that operating costs can be high for wet collectors in relation to other collectors due to water usage, corrosion, and the chemical treatment needed for water. Also, the high energy units, such as venturis, require a high power usage.

Another disadvantage is that since the cleaned gas exiting from the foundry is saturated with moisture, a plume of condensed steam develops which is visible until the vapor trail evaporates.[6] This condition can be mitigated through the use of additional de-misters. Furthermore, submicron dust sizes are difficult to extract in dewatering equipment. Acid pickup from burning coke and oil from scrap also occur.

If complete control of all solid emissions is required at a later date, it is often impractical to make certain equipment modifications to wet collectors such as use of aftercleaners. However, there have been instances where medium energy systems have been designed with the intent of making future equipment modifications to increase cleaning capabilities. Finally, due to the need for conservation of water, additional equipment for circulation and clarification is required.[2]

(f) Limitations of Wet Collectors

Exhibit VII-13 indicates the smallest particle that can be collected by the seven types of wet collectors. As shown, static washers are not capable of collecting dust particles under 10 microns in size and thus have the greatest limitations in this regard. Conversely, venturi scrubbers, being able to collect particles as small as 0.5 microns in size, have the least limitation.[4]

Wet collectors are not applied for collection in certain foundry areas such as boiler fly ash, pouring, mold cooling[5] and pulverizing. Also they are rarely used on woodworking and oil burn-off furnaces.[1]

Capacity ranges available for the different types of wet collectors are also shown in Exhibit VII-13.[4]

Wet collectors have no practical limitation regarding temperature or moisture conditions that may exist during operation.[6]

Fabric Filters

(a) Historical Background

Until the mid-1930's, foundry fabric collectors consisted of large U-shaped frames, originally of wood, to which a cotton cloth or canvas was tacked or otherwise attached to both sides of the structure. Panels were installed vertically with the top sealed to an adjacent header so dust-laden air was forced through the fabric with the cleaned air gathered in the inside of the support structure and exhausted through the open top. Periodically, the collector was stopped and the accumulated dust load dislodged by vibration.

During the early 1930's, design improvements were introduced to provide more effective vibration of the filter cloth, more positive seals between fabric and support, and faster media replacement. It was during this period that the current concepts of the envelope and cloth tube types were developed. Sectionalized, continuously operated collectors were a logical refinement for larger foundry applications where the collector could not be stopped with the frequency needed to maintain the desired exhaust flow.

It was the pressure on the industry by the Los Angeles Air Pollution District that generated the use of glass fabric for cupola gas cleaning during the late 1940's and early 1950's. Typical early installations consisted of relatively crude designs where long tubes were suspended from a mechanism that was manually operated to "rock" the tubes during shutdown. Production of glass cloth with a silicone lubricant permitted this mild flexing action without rupture of the glass fibers. The sensitivity of glass fabric to flexing encouraged the development of collectors of the reverse flow concept to provide more effective collected dust removal and continuous operation of the collector.

Fabric filters for electric arc furnaces in the gray and malleable iron foundry use exhaust control methods and generally orlon or dacron fabric based on practices developed in steel foundries. Local exhaust hood concepts date back to development work by the farm implement industry foundries in the mid-1940's. While medium pressure loss wet scrubbers were used on early installations, they gave way to the higher efficiency of the fabric filter by the mid-1950's for electric arc furnace fume collection.[5]

(b) General Characteristics of Equipment

The basic principle of fabric collection consists of dust-laden air passing through a filter media. The media acts as a base to build a mat of the collected material on the dirty air side. As the dust builds up on the fabric, resistance to airflow increases. Periodically, the airflow must be stopped and the accumulated cake removed. This can be done by vibrating the bag and letting the dislodged material fall into a hopper. It can also be accomplished by using reverse or secondary airflows.

Fabric filters are quite versatile in their contaminant removal capabilities. Since particles as small as 0.2 microns in size can be captured, excellent collection efficiencies can be achieved. Furthermore, dust concentrations can be heavy or light and capacity ranges can also vary with minimum effect on efficiency.

A significant factor regarding operation of fabric filters is the ratio of cubic feet per minute of air handled in the system to the square feet of cloth area of the collector. This is usually referred to as the air to cloth ratio. By lowering the ratio, less air velocity through the fabric is achieved, and bag wear decreases. However, economic factors also need to be considered in determining the ratio.[4]

The filter cloth is usually a specially woven cotton. However, dacron or orlon is used for temperatures reaching 225° F, and glass for 550° F temperatures. The units must be operated above the dew point temperature of the airstream so that moisture does not form to produce a mud cake to hamper air passage through the media.[1, 4, 5]

Two basic types of cloth filters are available--the flat- or envelope-type bag and the tubular-type bag. The flat- or envelope-type bag generally provides a more compact filter and better cleaning because the flat bag is kept taut. Dust is collected on the outside surface of flat bags. They also require a rigid framework so that collapse of the bag can be prevented. Exhibit VII-14 illustrates a flat-type bag used on a fabric filter.

The tube- or stocking-type bag is suspended from the shaker mechanism at the top and fastened on the bottom. Dust is captured on the inside of the tube.[7] Exhibit VII-15 shows a tube unit.

The key to successful operation and continued efficiency of fabric collectors is planned maintenance. Bags need to be inspected for leaks and cleaned. Shaker mechanisms and baffle plates have to be checked for proper cleaning action and wear. The valves and fan also require inspection to determine if they are functioning properly.[1]

The results of numerous investigations performed on dust separation processes with fabric filters can be summarized as follows:

- With increasing temperature, the collection efficiency drops and the filter resistance increases.
- The separation of particles larger than 0.5 microns takes place through an impingement and a sieving effect. Particles smaller than 0.5 microns are separated mainly by diffusion and electrostatic forces.
- The separation of particles takes place mainly on the outer surface of the filter fabric. The filter resistance naturally increases with thicker filter fabric, but the collection efficiency does not improve in the same proportion.
- The smaller the diameter of the fibers, the smaller the particles which can be separated. Stronger fibers have to be incorporated into technical filter fabrics for strength.
- The filter resistance of fabrics is directly proportional to the air or gas throughput.[2]

(c) Description of Specific Types

Three types of fabric filters used are: intermittent, continuous automatic, and reverse jet continuous. The basic principle of fabric collection previously described applies, in general, to each of the three systems except for bag cleaning.

1. Intermittent - This unit type lends itself to collection of widely scattered dust of an intermittent nature where the entire system can be shut down periodically to be cleaned. This type of collector can be used on any system that can be interrupted or bypassed during the cleaning cycle. Either the fabric filter, vibrating mechanism and exhaust fan are packaged in one unit or the exhaust is separate.

The intermittent-type collectors in the smaller sizes often are factory assembled, eliminating the need for field erection. Larger fabric collectors are available that contain up to 12,000 square feet of cloth area. Field erection of these units is required in many cases.[4, 5]

Exhibit VII-16 shows an example of an intermittent collector.

2. Continuous Automatic - With a continuous automatic-type collector, one section of the collection system can be shut down and remaining sections will continue to operate. The system consists of multiple collection sections, usually not less than four or six, each of which can be programmed to clean for a desired time period, progressing through the entire collector automatically. High concentrations of dust can normally be handled and a fairly uniform pressure drop is achieved with this type of unit.[1, 4]

Some reverse flow designs rely on flexing during collapse and reinflation to dislodge collected dust without mechanical vibration. In these designs, the reverse flow of air through the bag has to be carefully controlled or it could damage the bags. A sudden full reinflation of the collapsed bag could result in bag failures at the points where severe fiber flexing occurs such as along the edge of a seam. One manufacturer handles this problem by gradually introducing the flow of reverse air. Then, the reverse air valve is kept open temporarily when the filtering process begins, to allow a gradual buildup of pressure. Once the proper pressure is restored, the reverse air valve is closed.[5, 10]

Continuous automatic-type systems require additional equipment such as spare sections, damper assemblies, multiple shaker units and field assemblies.

Also, the damper and shaker units require additional maintenance.[1] An example of a continuous automatic system is shown in Exhibit VII-17.

3. Reverse Jet Continuous - Reverse jet continuous units are used where a high concentration of fine particles is being collected or where the material must be continually collected. This unit utilizes a secondary source of air to dislodge the dust cake. As the dust particles accumulate, airflow resistance through the filter increases. At a predetermined resistance level, a high velocity air jet penetrates the filter tube through a blow ring moving along the tube. This air jet, combined with the flexing action of the filter tube, dislodges

the accumulated dust which is then carried down into a hopper.[1, 4]

Secondary air is provided through use of an attached blower. One manufacturer's design utilizes an externally located pressure blower that is connected to the main collecting unit by a flexible heavy-duty, industrial-type hose. With the pressure blower, various types of air intake filters are used to control incoming air. Environmental dust conditions and the specific maintenance requirements of the system are two factors determining the type of air intake filter to use.[11]

The advantage of this system is that cleaning is usually more efficient than shaking. Also, less cloth area per cubic foot per minute is required compared to other fabric-type collectors. Operating costs and maintenance expenses are reportedly higher than shaker-type fabric collectors.[1, 4]

Exhibit VII-18 illustrates a reverse jet continuous fabric collector.

(d) Advantates of Fabric Filters

Well-designed fabric filter installations provide excellent collection efficiency on dust particles down to 0.2 microns in size and can be designed to handle large gas volumes. In addition, dispersion of exit gases into the atmosphere does not present a steam plume problem.

Fabric filters normally operate with a low pressure drop, three-inch to five-inch, and, therefore, have low power requirements. Fabric units are not normally subject to corrosion, and furthermore, no disposal of waste water is required.[1, 4]

(e) Disadvantages of Fabric Filters

Initial equipment and erection cost can be high and large space requirements are usually necessary. Filter bags need periodic replacement, adding to the maintenance costs. Added safety precautions are sometimes necessary for cleaning inflammable gases. Furthermore, there is the danger of temperatures sinking below the dew point as a result of evaporative cooling which would cause moisture to form and clog filters. Carry-over of glowing particulate matter represents a danger to natural or synthetic fiber bags.

Dry material disposal can be a problem as particle sizes of collected material decrease. Refuse handling and secondary dust dispersion are factors that must be considered in this regard.[1, 2, 4]

(f) Limitations of Fabric Filters

In a normal installation, the smallest particle size that can be effectively captured by a fabric filter collector is approximately 0.2 microns in size. Special equipment modifications could result in increased efficiencies.[4]

There are temperature limitations that must be maintained with respect to different fabrics as shown on the following page.[49]

Fabric	Melting Temperature	Recommended Maximum Continuous Operating Temperature
Cotton	Decomposes at 302° F	180° F
Wool	Chars at 572° F	200° F
Nylon	480° F	200° F
Dacron	482° F	275° F
Nomex	Decomposes at 700° F	350° F
Orlon	Softens at 482° F	260° F
Creslan	Softens at 475° F	250° F
Dynel	Softens at 325° F	160° F
Polypropylene	333° F	200° F
Teflon	Decomposes at 750° F	400° F
	Emits toxic gas at 450° F	
Fiber glass	1,470°	550° F
Filtron	Softens at 505° F	270° F

Fabric filters are not applied for collection in certain foundry areas such as boiler fly ash, pulverizing and oil burn-off furnaces, nor are they suitable for handling emissions from oily scrap and phenols from shell molds and cores.

Pertaining to capacity ranges, small intermittent fabric collectors are designed to handle from 300 to 2,000 cubic feet per minute. Capacity rates can be varied quite widely for large intermittent, continuous automatic and reverse jet continuous-type fabric collectors.

Fabric materials have certain limitations that appear noteworthy. Wool is not suitable when dirty gases contain tar or have an acidic effect. Glass fabrics are less flexible than wool and cannot withstand strong mechanical stresses. Finally, glass is not suitable for handling fluoride compounds since the lubricants and fibers are subject to chemical attack.[1, 2, 4]

Electrostatic Precipitators

(a) Historical Background

The first effective electrostatic precipitator was designed in 1883 for cleaning top gases from a blast furnace. Since production of direct voltage through friction was unsatisfactory, further application was not attempted at that time. In 1906, an electrostatic precipitator was introduced that used a mechanical high voltage rectifier. In 1916, a dry-type precipitator was designed followed by wet systems shortly thereafter.[5]

The electrostatic precipitator for cupola gas cleaning has been more widely accepted in Europe than in the United States where the trend in recent years has been strongly in favor of high energy wet scrubbers. Only two precipitator installations in foundries have been reported in this country in the last two years--one in Texas and the most recent in Indiana.

(b) General Characteristics of Equipment

This type of collector utilizes high voltage, low amperage direct current for operation. A complete system usually consists of the following: precipitator housing, discharge electrode, collecting electrodes, gas distribution system, cleansing devices, dust and sludge removal and electric power supply facilities. Wires or rods are suspended from an overhead high voltage-charged grid between grounded plates. These wires are hung on approximately 2- to 3-foot centers and carry 50,000 to 100,000 volts. When the voltage reaches the corona stage, the gases passing through are ionized, forming negative and positive ions. With the wires negative and the plates positive, the negative ions travel across to the positive collecting plates and in the process negatively charge the dust particles which also then are attracted to the positive plates. Removal of dust particles varies depending on whether the unit is a wet- or dry-type precipitator.

Performance of electrostatic precipitators essentially depends on the characteristics and relationship of the suspended particles, velocity of the gas passing through the collector and electrical resistivity of the material deposited on the electrodes.

Pertaining to the suspended particles, it is important to know their size, amount of particles in suspension and chemical analysis. Particle size will have a bearing on whether primary collection preceding the precipitator is required. The amount of particles in suspension has an effect on design efficiency required to meet emission codes. Chemical composition relates to particle size since some nonferrous metals product fine particles.

The velocity of the gas passing through the collector is determined by the length of time the particulate matter must remain in an electrical field. This period determines the number and size of collection tubes needed to treat the total volume of gas at this velocity.

Electrical resistivity pertains to the measurement of the ability of a particle to resist an electrical unipolar charge. This measurement indicates the amount of conditioning necessary and the length of time a particle needs to remain under the influence of the electrical field. Resistivity varies over a wide range depending on the temperature and moisture content of the gases.[1, 2, 4]

(c) Description of Specific Types

Electrostatic precipitators can be either wet- or dry-type collectors:

1. Wet Type - These units usually consist of a circular shell or casing that is divided into two gas compartments by a header plate. Suspended from the header plate are a number of tubes that form gas ducts. Discharge electrodes are suspended in the tubes from an insulated framework. Dirty gases pass from the lower compartment through the tubes for cleaning and then into the upper compartment. Dust particles are then removed from the surface of the collecting pipes by water flushing.

The discharge electrodes are energized by electrical equipment consisting of a manual or automatic control unit, high voltage transformer and rectifying equipment. Control equipment is usually all electronic. Power level or sparking rates act as electrical feedback signals that activate the control equipment. With this type of equipment system, electrical input under varying process conditions such as temperatures, flow rates, dust particle size and resistivity is optimized. Rectifying equipment can be either mechanical, motor driven, electronic or solid state.

Wet-type units are frequently built vertically. In this arrangement, gas flows through the filter in a vertical direction and normally from bottom to top. This results in a longer period of stay for dust particles in the collector because of the gravitational force and produces better separation of coarse particles.[1, 2, 4]

Exhibit VII-19 indicates a wet-type electrostatic precipitator gas cleaning system.

2. Dry Type - The basic structure of these units consists primarily of a rectangular shell or casing from which are suspended a number of collecting electrode plates. These plates are parallel to each other and equally spaced to form channels through which gases pass. High tension discharge electrodes are suspended vertically in the center of the channels. Collected material is removed from the surface of the collecting electrodes by a continuous rapping device.

Dry process electrostatic precipitators are usually built on a horizontal basis. A horizontal arrangement allows the gas to move in this direction which facilitates the cleaning of collecting electrodes by means of rapping or shaking. Dust does not fall against the gas stream but only at right angles to it.

The rapping mechanism usually consists of a number of hammers that are driven pneumatically or by means of impact shafts striking against the electrodes in regular intervals. The electrodes can also be deflected horizontally out of their normal position over a cam shaft and then made to strike against an anvil. The discharge electrodes are rapped with hammers that are lifted by tie rods and then released. Regular maintenance is necessary for the electrode rapping equipment.

The collecting electrodes should represent a freely oscillating system with a minimum damping capacity. This allows a uniform distribution of the oscillations over the plate surface, so that particles of all sizes can be removed from the electrodes during rapping.[1, 2, 4]

A dry-type electrostatic precipitator gas cleaning system is illustrated in Exhibit VII-20.

(d) Advantages of Electrostatic Precipitators

These unit types provide excellent removal of solid particles when the collector is properly designed to enable such performance. Power requirements are substantially less for electrostatic precipitator units than for other induced draft collection systems.

Furthermore, these collector types can be designed to handle moisture, oil and similar conditions that are unsuitable for certain other collector designs. Finally, these units are flexible in that additional cells can be added to existing equipment to meet changing process requirements or more demanding codes.[1, 2, 4]

(e) Disadvantages of Electrostatic Precipitators

For small gas volumes--50,000 CFM or less--costs are disproportionately high on a per CFM basis because of power equipment and engineering cost requirements if the unit is not an "off the shelf" design. Maintenance expense is greater than units having a lower order of collection.

Gas temperatures and water vapor content need to be closely controlled due to the resistivity characteristic of particles. Fluctuations of cupola stack temperature can make it difficult to maintain proper temperature of gases going to the collector.

If the effluent emitting from the cupola contains iron and silicon oxide and the collector is operating at temperatures of 300° F or above, problems could develop. At these temperatures, the resistivity of silica will increase to the point where it is necessary to condition the gases, by adding moisture. This moist condition will accommodate silica, but the iron oxides will tend to coagulate on the collector plate and be difficult to remove.

Other disadvantages are that a precleaner is sometimes necessary for heavy loads and a dry dust disposal problem may develop. Finally, there is a potential risk involved with using high voltage equipment.[1, 2, 4, 12, 13]

(f) Limitations of Electrostatic Precipitators

The smallest particle that can be collected with a normal electrostatic precipitator installation is 0.1 microns in size. Increased efficiencies are possible through equipment modifications.

These collectors are limited in their application to different foundry processes and consequently have been very rarely used. Furthermore, these units should not normally be used when temperatures exceed approximately 700° F.[1, 2, 4]

Collection Efficiency of Emission Control Equipment Systems

The success of a control equipment system will depend upon its ability to remove sufficient emissions to provide an acceptable order of cleanliness. Criteria for evaluating collection efficiency will be determined by the objective of the system and often by regulations defining acceptable emission levels.

Accurately defining equipment efficiency is difficult since inlet loadings vary widely in concentration, particle size ranges and dust composition for most foundry operations. This occurs not only between similar operations in different plants, but also with any given application, almost minute by minute during a normal working day. Consequently, designers of control equipment find it difficult to define exit or cleaned gas conditions other than as a function of incoming particulates. The lower the order of collector performance, the more difficult it will be to predict exit conditions except in terms of overall percentage of removal or percentage removed by particle size fraction.

Yardsticks used to express collection efficiency of emission control equipment include: (a) weight, (b) particle size count, (c) opacity and (d) ground level concentration.[5]

(a) Weight

The most acceptable yardstick for expressing collection performance is on the basis of the weight of emissions collected. Different scales are used in this regard including pounds per hour, pounds per unit of process weight (tons melted, and sand conditioned), pounds per 1,000 pounds of gas and grains per standard cubic foot of gas.[5]

Regarding the grains per standard cubic foot of gas scale, performance is calculated on the basis of the ratio of weight of particulate per unit of gas entering the collector to the weight of particulate per unit of gas trapped in the collector. This ratio is then expressed as a percentage. An example of how efficiency is calculated in this manner is given in the tabulation shown on the following page.

Dust entering collector -- 1.0 grain/cubic foot
Dust leaving collector -- 0.1 grains/cubic foot
Dust trapped in collector-- 0.9 grains/cubic foot

Thus, 0.9 grains/cubic foot divided by 1.0 grain/cubic foot = 90% dust collector efficiency.[4]

Exhibit VII-21 indicates relative efficiencies of collector systems based on outlet loadings in grains per cubic foot of gas for various foundry applications. These are typical performances that can vary based on differences in melt charge, dust characteristics, particle size distribution, collector design and numerous other factors.[1] By referring to the figures on Exhibit VII-21, collectors can be ranked according to efficiency as shown on the following tabulation.

Type Collector	Collection Efficiency
Fabric Filter	Highest
30"-70" wet scrubber and electrostatic precipitator	
6"-30" wet scrubber	↕
Low efficiency cyclone	
Wet cap	Lowest

These efficiency rankings are general, overall indications that are not related to costs, collector design, specific applications or other factors. They are simply an indication of the relative performance that has been experienced with these systems.

(b) Particle Size Count

A count of particle sizes collected is another method widely used to express efficiency of collection equipment. This requires knowing the fractional efficiency of a collector at various micron size ranges and also the particle size distribution.

Particle size efficiency curves are available for most commercial collector designs, although any such base curve must be modified for the influence of particulate concentration, particle shape, specific gravity, chemical characteristics and various other factors to fit a specific situation. Where inlet conditions cannot be accurately specified because of variable composition and rate of contaminant release, new processes not yet in operation, or high cost of data development, specification of collector performance on a fractional basis is usual.[5]

A convenient way of comparing relative performance of various collectors by this method is to determine overall collection efficiency based on a standard test dust. This was accomplished by 1956 and the test results are presented in the following paragraphs.

The test was conducted on a silica powder which has a grading about the same as typical fly ash from a pulverized fuel boiler. The grading of this dust is shown in Exhibit VII-22. As shown in the exhibit, the largest percentages of dust were in the 20- to 75-micron size ranges and also under 2.5 microns.

Based on this standard dust, collection efficiency was then calculated for various collectors, the results of which appear in Exhibit VII-23.

The efficiencies shown at five microns were taken from grade efficiency curves developed for each collector.[14] A ranking of overall collector efficiency based on these results is shown in the following tabulation.

Type Collector	Collection Efficiency
Fabric filter	Highest
Venturi scrubber	↑
Wet impingement scrubber	
Electrostatic Precipitator	
Spray tower	
Self-induced spray deduster	
High efficiency cyclone	↓
Medium efficiency cyclone	Lowest

As discussed previously, these figures serve to place the collectors in order of merit in terms of collection efficiency only. A more meaningful assessment includes consideration of costs and other relevant factors.

(c) Opacity

Opacity, or discharge appearance from a stack, is another yardstick often used to measure collection efficiency of control equipment. The Ringelmann Scale shown in Exhibit VI-1 is one of the most commonly used measures of this type.[1]

A major limitation of opacity measures, which were discussed in Section VI, is that discharge appearance from a stack will seldom indicate the degree of collection. For example, where only coarse particles are released, such as snag and portable grinding, there would be no visible escapement if exhausted dust were discharged to the atmosphere without collection equipment. On the other hand, removal of 90% of the metallic oxides generated by the electric arc furnace could make little or no reduction in the visible plume.

Because acceptable discharge appearance for most foundry processes occurs where solid concentrations do not exceed 0.05 grains per cubic foot of gas, this weight measure is often substituted for performance in terms of equivalent opacity.[5]

(d) Ground Level Concentration

The objective of air pollution and public nuisance legislation is, in part, one of controlling the air quality at ground level. However, measured in terms of tons per square mile, micrograms per cubic meter, or as a soiling index, it can only indirectly be related to the condition of a discharged quantity of process air because of diffusion, turbulence, wind velocity and direction, and contributions from other sources.[5]

Factors Affecting Control Equipment Collection Efficiency

A number of operating conditions and other factors affect gas cleaning performance. Certain of these have more effect on efficiency than others while some conditions are difficult to evaluate because of limited factual knowledge on their influence. Furthermore, some conditions appear to affect all control systems while others affect only one or a few systems.

1. Melting Operations - The cupola melting operation results in exhausting large volumes of high temperature gas laden with dust particles and fume. It is difficult to arrive at valid generalizations on how melting operations affect collection efficiency as evidenced from the following statements:

> It would be helpful to the average foundryman if an average emission load from the cupola melting operation could be established. This is impossible, however, due to the varied operations from one foundry to another, and due to the complex melting cycle, metal composition and operations of various foundries.... The volumes of gas exhausted and the quantities of coarse and fine materials making up the total emission vary in cupola operations depending on melting rate, charging methods and cleanliness of materials. 15

This conclusion was also reached in an analysis of cupola furnace metallurgy. It was found that values for coke rate, blast volume, and blast temperature generally applied in practice result in such widely varying melting conditions, that a universally valid statement on the effect of chemical constituents in charge materials on the characteristics of the reaction products, namely gas dust, cannot be made.

This problem is further exemplied from the following findings:

> The raw gas contents ascertained during the...survey did not show any relationship

> between dust content on the one hand and coke rate and specific melting rate on the other.... The dust content of the waste gas from basic hot blast cupolas was especially high on account of the large proportion of small-sized steel scrap material in the burden. If one calculates the corresponding dust emission per ton of iron from the top gas dust contents, there appears to be an increase with increasing coke rate.... Because of uncertainties in the calculation of top gas and waste gas quantities per ton of iron in each case, many of these values are not very reliable.2

It can be established that one of the factors affecting collector efficiency is the raw gas dust content. Furthermore, it has been shown that data are incomplete on the effect of melting operations on dust content, except for the generalization that dust content is influenced. Therefore, it can be concluded that melting operations affect collector efficiency, but the exact degree of influence is unknown at this time.

2. Gas Flow Rate - Gas flow rate variations result in velocity changes and thereby influence control equipment efficiency and pressure drop. The influence on efficiency varies with the control system being considered.

With dry centrifugal cyclones, the degree of particle collection is proportional to the amount of centrifugal force exerted on dust particles in a waste gas stream. In conical portions of a cyclone, centrifugal force, and thereby collection efficiency, is greatest at high gas velocity and with a small cyclone diameter. However, there are limitations to this application. In a cyclone operation, there is an inlet velocity beyond which turbulence increases more rapidly than particle migration to the wall. When such conditions are reached, with further increases in flow rate, collection efficiency actually decreases.[16]

Pertaining to wet collectors, the following statement indicates the effect of gas flow on efficiency.

> The faster the particle is traveling, the less likely it is to avoid collision. Therefore, the efficiency in scrubbers is a function of the velocity in the collection area, which in turn is related to the overall pressure drop. So, high energy scrubbers in general are more efficient than low energy scrubbers.[1]

In the operation of fabric filters, the velocity at which the gas passes through the fabric must be low. This is because higher velocities lead to compaction of the dust cake, which results in high pressure drop, or worse, in breakdown of the filter bed, allowing coarse particles to pass. Therefore, to enable normal bag filters to operate at high efficiency, it is necessary to provide large areas for filtration and avoid frequent cleaning. The reverse jet filter overcomes this limitation to a great extent by removing deposited dust by a reverse current of air. Thus, the buildup of dust is avoided which eases the limitation on operating velocity.[14]

Fabric filters are adaptable to gas rate variations because a barrier for particulate removal is developed. However, these systems are subject to pressure drop variations and generally speaking, the cleaning system will not deliver at a constant rate when the pressure drop increases.[17]

Gas flow rates affect electrostatic precipitator performance in that the higher the migration velocity of the gas, the larger the increase in collection efficiency. Further factors must be considered in this regard, though, including:

- Surface area.
- Particle composition and chemical analysis of dust.
- Characteristic curve of current and voltage.
- Flashover frequency.
- Velocity and pressure in precipitator.
- Gas composition, temperature and moisture.
- Dust resistance.[2]

Finally, optimum gas flow velocities have not generally been established with certainty for any of the control processes because they are greatly influenced by properties of dust and carrier gas as well as by the design of the collection equipment.[17]

3. Carrier Gas Temperature - Gas temperature has a principal influence on the volume of carrier gas. This, in turn, influences the size and cost of the collector and the concentration of the contaminant per unit of volume. Furthermore:

> In electrostatic precipitation, both dust resistivity and the dielectric strength of the gas are temperature dependent.
>
> Wet process cannot be used at temperatures where the liquid would either freeze, boil, or evaporate too rapidly. Filter media can be used only in the temperature range within which they are stable. The structure must be of materials that retain their integrity at their operating temperatures.
>
> Last, low temperature gases from a stack following control equipment disperse in the atmosphere less effectively than high temperature gases. Consequently, benefits derived from partial cleaning accompanied by cooling

> may be offset if the cool stack gas cannot be well dispersed. This is a factor of importance in wet cleaning processes for hot gases, where the advantage gained by cleaning is sometimes offset near the plant by downwash from the stack because the stack gas is cooled.[17]

4. Carrier Gas Pressure - Pressure of the carrier gas is not of prime importance in particulate collection except for its effect on gas density, viscosity, and electrical properties. It could be a factor, however, in deciding whether a high energy wet scrubber or another type of control system is best suited for a particular application. An available source pressure can be used to overcome the high pressure drop across the scrubber, reducing the high power requirements that could limit the use of scrubbers.[17]

5. Carrier Gas Viscosity - This gas property has an effect on efficiency as shown below:

> Viscosity is of importance to collection techniques in two respects. First, it is important to the removal mechanisms in many situations (inertial collection, gravity collection, and electrostatic precipitation). Particulate removal techniques often involve migration of the particles through the gas stream under the influence of some removal force. Ease of migration decreases with increase in viscosity of the gas stream. Second, viscosity influences the pressure drop across the collector and thereby becomes a power consideration.[17]

6. Carrier Gas Humidity - Gas humidity affects the performance of control systems as evidenced in these statements:

> High humidity may contribute to accumulations of solids and lead to the caking and blocking of inertial collectors as well as

> caking on a filter medium. It can also result in cold spot condensation and aggravation of corrosion problems. In addition, the presence of water vapor may influence the basic mechanism of removal in electrostatic precipitation and greatly influence resistivity. In catalytic combustion, it may be an important consideration in the heat balance that must be maintained. Even in filtration, it may influence agglomeration and produce subtle effects.[17]

7. Electrical Properties of Carrier Gas - This is a factor regarding electrostatic precipitators because the rate or ease of ionization influences particle removal. The intensity of Brownian motion, which states that particles in motion in the neighborhood of the collecting droplets diffuse to them and are intercepted, and gas viscosity, both increase with gas temperature. These factors are important characteristics that relate to the sonic properties of the gas stream. Increase in either property will tend to increase the effectiveness with which sonic energy can be used to produce particle agglomeration.[17]

8. Dust Composition - An analysis of cupola dust composition from different foundries is tabulated in Exhibit VII-24. As indicated by these results, dust composition varies quite widely. This is important with respect to collector efficiency since dust constituents with higher specific weights will sink down easily in air as a result of mass forces. Also, the carbon content of dust makes wetting more difficult and thus puts higher requirements on wet scrubbers.[2]

9. Dust Loading - Dust loading will influence different types of collectors in different ways. For example, cyclone efficiency will increase at higher dust loadings, but extremely

high loading may overtax the rapping and shaking mechanism of fabric filters and electrostatic precipitators. Furthermore, processes such as sonic agglomeration are quite sensitive to changes in dust loading.[17]

10. Dust Solubility - This factor is important regarding absorption and scrubbing. In absorption, which relates to wet collectors, the degree of solubility is an indication of the ease of removal of the contaminant. In scrubbing, solubility will provide a secondary removal mechanism to assist the basic separating forces.[17]

11. Dust Sorbability - Sorbability, or the ease with which a contaminant can be removed in wet collectors by absorption, is a function of temperature, pressure of the system, chemical composition of the dust and sorbent and also solubility. The effect on efficiency varies depending on the interaction of these factors.[17]

12. Electrical Properties of Dust - Electrical and sonic properties are an influence in collector performance as the following evidence indicates:

> Electrical properties are considered to be a contributing factor influencing the build-up of solids in inertial collectors. In electrostatic precipitators, the electrical properties of the contaminant are of paramount importance in determining collection efficiency and influence the ease with which it is removed by periodic cleaning. In fabric filtration, electrostatic phenomena may have direct and observable influence upon the process of cake formation and the subsequent ease of cake removal. In spray towers or other forms of scrubbers in

which liquid droplets are formed and contact between these droplets and contaminant particles is required for particle collection, the electrical charge on both particles and droplets is an important process variable. The process is most efficient when the charges on the droplet attract rather than repel those on the particle. Sonic properties are significant where sonic agglomeration is employed.[17]

13. Dust Toxicity - The degree of dust toxicity will influence collector efficiency requirements and may necessitate the use of equipment that provides exceptionally high efficiency. However, the removal mechanism of the collector is not affected by toxicity.[17]

14. Particle Size, Size Distribution, Shape and Density - The size, shape and density of particles are the properties that determine the magnitude of forces resisting movement of a particle through a fluid. These forces are a major factor in determining the effectiveness of removal by collection systems. Furthermore, these forces are balanced against some removal force applied in the control device and the magnitude of the net force for removing the particle will determine the effectiveness of the collection equipment.

Size, shape and density of particles are related to terminal settling velocity which is significant in selecting control equipment. This relationship is expressed by Stokes law which equates the velocity at which particles fall at a constant speed because of a balance of the frictional drag force and the downward force of gravity to the properties of the particle and the viscosity of the fluid through which it settling. The equation for Stokes law is:[17]

$$V_t = P_p g d_p^2 / 18uf$$

where: V_t = terminal settling velocity in centimeters/seconds

P_p = particle density in grams/cubic centimeter

g = acceleration due to gravity in centimeters/seconds 2

d_p = particle diameter in centimeters

uf = fluid viscosity, poise in grams/centimeter second

This equation is for particle sizes less than 100 microns.

Particle size and size distribution are especially significant with regard to collection efficiency as shown below:

> Any dust collector, operating under specific flow conditions and with a given gas, will have a collection efficiency corresponding with each particle size or particle size-distribution passing through the collector.[16]

Particle size distribution of dusts found in air pollution work satisfies the normal standard distribution curve.

Additional conclusions on the effects of particle size on efficiency appear relevant.

> The effect of particle size on efficiency of a collector can be demonstrated by collecting dust samples on the inlet and outlet of the operating collector. Knowing the inlet and outlet dust concentration and the inlet and outlet size distributions, collection efficiency can be plotted as a function of particle size on arithmetic coordinates. The resulting plot, known as a "size-efficiency" curve, describes the performance capabilities of the collector in question when operating at stated gas flow conditions (velocity, viscosity, etc.).

> The collector would have a different "size-efficiency" curve for each new gas flow condition, but the curve would remain unchanged for different dust concentrations and different size distributions. Thus, for any particle size passing through a given collector, a definite and predictable collection efficiency will be observed, flow conditions remaining constant. "Size-efficiency" curves are especially useful in predicting overall collection efficiency for a specific dust having known size-distribution characteristics.17

Typical examples of how particular gas cleaning equipment efficiency is affected by particle size and particle size distribution is presented in the following discussion.

Exhibit VII-25 gives the typical grade efficiency curves for a high efficiency cyclone and electrostatic precipitator. The density of dust that the curves are based on is 2.7 grams per cubic centimeter. Fractional efficiencies for various micron size ranges were then read from these curves and applied to a standard test dust shown in Exhibit VII-22. These results are shown in Exhibit VII-26.

As shown in Exhibit VII-26, the percent of dust distribution in each micron size range times the percent efficiency for that range gives an overall collection efficiency per range. The sum of these individual range efficiencies equals the overall efficiency for the collector. In this particular test, the cyclone collector was followed by an electrostatic precipitator in one total installation rather than each system tested individually.

Particle size has an interesting effect on efficiency of fabric filters, as Exhibit VII-27 indicates. Theoretically, efficiency is approximately 100% at zero micron size but dips down to 10% for 0.9-micron particles and then increases back to 100% again at 1.6 microns. The reason for the dip is that impingement and diffusion effectiveness is lowest at approximately the 0.9-micron size.[14]

Another interesting effect that particle size (and the length of time a fabric is in use) has on fabric filter performance is also shown in Exhibit VII-27.[18]

When new fabric has been placed in service, efficiency will be low until dust cake builds up. After cleaning, once the fabric is loaded, there is still sufficient dust adhering to the fabric to maintain the dust mat needed for efficient collection and the collector will perform in the normal operating range.

The relationship of particle size, pressure drop and efficiency of venturi scrubbers is shown in Exhibit VII-28.

As shown, pressure drop has a significant effect on efficiency with respect to all particle sizes.[17]

Combustion Devices

In addition to basic emission control equipment systems, combustion devices can be used to control foundry pollutants.

(a) Afterburners

This equipment, used on cupolas, can consist of a combustion chamber, gas burner, burner controls and temperature indicator. In an afterburner operation, contaminated gases are mixed thoroughly with the flames and the burner combustion gases in the afterburner throat. Next, the gases pass into the main section of the afterburner where velocity is reduced. Combustion reaction is then completed and the incinerated air contaminants and combustion gases pass out of the cupola.

It is important to position afterburners properly so that complete mixing of gases will be achieved. In addition, sufficient oxygen must be available to burn all combustible contaminants completely and ignition time has to be provided in the cupola stack. A distance from the top of the charging door to the top of the stack of at least 25 feet is usually required for proper combustion.

Afterburners are used to complete oxidation of combustible contaminants in cupola melting operations. In this regard, the burning of carbon monoxide into carbon dioxide reduces the explosion hazard. Afterburners also reignite gases that may be extinguished by a cupola charge or charging bucket. The advantage from a public relations standpoint of a reduced discharge appearance by using afterburners usually will outweigh the formation of some additional dust particles through the reduction of coke cinders to ash.

Efficiency of afterburners essentially depends on the degree of mixing of contaminated gases with the flames and burner combustion gases within the afterburner unit. Also important in this regard are operating temperature, retention time of gases within the afterburner and concentration and types of contaminants to be burned.

Afterburners are often used in conjunction with basic emission control equipment systems. They are especially useful when the cupola charge contains oils, as the greater portion of visible smoke comes from unburned oils.

Afterburners have limitations in that cupola exhaust gases with carbon monoxide in certain concentrations need to be in a temperature range of approximately 850° to 900° F. This is important since exhaust gases must be heated to approximately 1200° to 1400° F to initiate oxidation which means that fuel costs for operating afterburners can be excessive if too much heating is required.[1, 6, 19] Exhibit VII-29 illustrates a typical afterburner unit.

(b) Catalytic Afterburners

This process, used on bake ovens, consists of an afterburner housing containing a preheating section, if required, and a catalyst section. Frequently, contaminated gases are delivered to the catalytic afterburner by the fan exhausting the oven. The gases then pass into the preheat zone where they are heated to the temperature required to support catalytic combustion. Here, some burning of contaminants usually occurs. The preheated gases then pass through the catalyst bed where the remaining combustible contaminants are burned.

The purpose of the afterburner is to complete the oxidation of combustible gases to an odor- and color-free condition before exhausting them to the atmosphere. These gases will burn at a temperature of 650°-1000° F, in the presence of a suitable oxidizing catalyst, such as platinum. A significant savings in fuel cost can be realized in the preheating of combustible gases to this lower temperature instead of the 1500°-2000° F required without a catalyst.

Efficiency of catalytic combustion units depends on several factors. Contact of gases with the catalyst, uniform flow of gases through the catalyst bed, temperature, catalyst surface area, nature of materials being burned and oxygen concentration are important in this regard.

A limitation of catalytic units is that, because of some materials of construction, these devices cannot be operated at temperatures necessary to produce complete combustion.[1, 19] Exhibit VII-29 depicts a catalytic combustion device venting a core baking oven.

APPLICATION OF EMISSION CONTROL EQUIPMENT SYSTEMS TO FOUNDRY PROCESSES

Although the majority of gray iron foundries currently do not have collection equipment systems for control of emissions from melting operations, the number of installations of these systems has increased rapidly the last few years. The 1967 survey conducted by the Business and Defense Services Administration and the National Air Pollution Control Administration indicated that 204 of 1,376 foundries had some type of emission control system for melting processes. Current estimates appear to indicate this figure has approximately doubled.[20] A tabulation of different emission collection equipment designs and their particular application to foundry processes is shown in Exhibit VII-30.

In addition to the many dust collection equipment systems in use, a variety of hoods, ventilating and exhaust systems and various other techniques are employed to capture or exhaust foundry emissions.

For purposes of discussion, the iron foundry has been divided into areas of activity in which characteristic emission control problems occur. These are as follows:

- Raw material handling, preparation and charge makeup.
- Cupola melting.
- Electric arc melting.
- Electric induction melting.
- Other types of melting.
- Inoculation.
- Mold pouring, cooling and shakeout.
- Sand preparation and handling.
- Cleaning and finishing.
- Coremaking.
- Miscellaneous areas.

Raw Material Handling, Preparation and Charge Makeup

The charge yard and charge makeup areas in most iron foundries have not normally been considered important sources of air pollution and therefore, with rare exceptions, have not had air pollution control systems installed. This has occurred for two reasons. Most of the emissions which come from these areas are dusts of relatively large particle sizes which settle readily. Second, few fixed emission points exist in typical yards where control can easily be applied. In a few cases, ventilation systems and dry centrifugal collectors have been installed in the charge makeup area, where it is located inside an enclosed building.

The one area which has been receiving attention in recent years involves those foundries in which metallic charge materials are either burned to remove nonmentallic coatings or accompanying nonmetallic debris, or are preheated to remove moisture or oily coatings. Since these operations are almost always performed in a fixed combustion unit of some type, emission control systems are relatively easy to apply. Medium energy wet collectors have been used where oil fume and vapor were present, and dry centrifugal collectors were applied where dry dusts existed.

Cupola Melting

Because of the widespread use of cupolas for melting, the severity and complexity of the cupola emissions problem, the difficulty of determining the nature and amount of emissions, and the generally high collection equipment costs, more attention has been devoted to emission control of this foundry process than any other. The presence of these factors as well as other variables such as the wide range of cupola operating characteristics has resulted in more control methods and techniques being employed on cupolas than on any other foundry process. In fact every known method, from simple spark screens to complicated systems such as electrostatic precipitators, has been tried with varying degrees of success. Although selection of cleaning equipment varies with the purpose of the installation, recent attention has centered on those techniques which have been most successful in high efficiency control of emissions, such as high energy wet scrubbers and fabric filter baghouses.

The problem of selecting gas cleaning equipment for cupolas depends essentially on the degree of efficiency required, need to meet existing pollution codes, and the economic factors of capital and operating costs.[1]

Wet caps, dry centrifugal collectors, wet collectors, fabric filters and electrostatic precipitators are the different collection systems which have been used for cupola emission control.

In the following paragraphs, the principal types of equipment in use on cupolas are briefly described.

(a) Wet Caps

These collectors, used more frequently on cupolas than any other type, are placed directly on top of cupola stacks and thus do not require any gas-conducting pipes and pressure-increasing blowers.[2] Wet caps are most practical in plants having an existing supply of low cost water and the ability to dispose of collected dust in sludge form.[4] Furthermore, some type of wet cap system is often employed in conjunction with high energy wet collector installations on cupolas.

Approximately 95 gray iron foundries were reported to have cupola wet caps in 1967.[20]

Once the most popular type of cupola emission control, the low efficiency of the wet cap has caused it to decline in use in recent years. Progress is now being made in developing higher efficiency wet caps with multiple spray sections.

(b) Dry Centrifugal Collectors

These low energy units are designed for light to moderate particulate concentrations. In a cupola installation, ductwork and an exhaust fan to draw gases to the collector are required. These systems also necessitate capping the cupola and installing a cooling spray to reduce the temperature of exhaust gases flowing to the collector. Often, dry centrifugal units are used as precleaners of hot blast cupola top gases prior to feeding into a recuperator.[21] Furthermore, this type of collector is an integral part of most high efficiency emission collection systems. In 1967, approximately 15 gray iron foundries reportedly had dry centrifugal installations which were not part of a larger cupola emission collection system. The low efficiency of the dry centrifugal collector has resulted in almost no new installations on cupolas in recent years, unless they were part of a larger system.

(c) Wet Collectors

Several different medium and high energy designs have been applied on cupolas. A wide range of capacities and collection efficiences is available. These systems are usually used where moisture and/or high temperature are present in the emission. A complete installation requires ductwork, an exhaust fan and capping of the cupola. As with wet caps, these systems are most practical where low cost water and sludge disposal equipment are available.[4, 21] Although only 30 gray iron foundries were reported to have cupola wet collectors in 1967, recent trends indicate that installations of this type of system are increasing more rapidly than any other.[20]

(d) Fabric Filters

When cupola collection efficiencies of 99% or higher are required, fabric filters are often selected. Although various fabric materials are available, glass fabric is typically chosen because of its resistivity to high temperatures. Complete installations can include numerous components such as a baffle, raised cupola stack and lid, ductwork, exhaust fan, spray coolers and other items in addition to the fabric filter unit. Another type of installation involves using heat exchangers instead of spray coolers. Fabric filter units can be installed to handle more than one cupola if desired.[21] Approximately 39 gray iron foundries were reported to be equipped with fabric filters on cupolas in 1967.[20]

(e) Electrostatic Precipitators

Rare applications of these systems have been made on cupolas. Excessive costs, and operating and maintenance problems have limited the use of these systems.[22] Only one gray iron foundry was reported to have a cupola electrostatic precipitator installation in 1967.[20] Additional installations have been made in the past few years.

(f) Other Techniques

In addition to application of the major classes of collection equipment, afterburners and preheaters can be used to control emissions from cupolas.

1. Afterburners - In cupola installations, afterburners or gas igniters can be employed for burning the combustible top gases, thereby reducing the opacity of particles discharged from the stack and for eliminating explosion hazards from cupola gases. Afterburners are located just below or opposite the charging door.[21]

2. Preheaters - Burning of unburned products of combustion can also be accomplished at times with a type of blast air preheater which burns exhaust gases from the cupola. Not only is thermal efficiency of the cupola capable of improvement, but the preheater acts as a settling chamber for collecting coarse dust.[21]

Electric Arc Melting

Compared with the cupola, electric arc melting has in the past received a great deal less attention regarding air pollution control for several reasons. Many of the emission problems for this process had already been substantially resolved with existing designs of equipment. Furthermore, electric arc melting accounts for a relatively small portion of total foundry melting in the United States, although this percentage is increasing rapidly. Finally the emissions from electric furnaces are substantially less than from the cupola.

A number of differences exist between the electric arc and cupola air pollution problem which are significant regarding control techniques. First, the electric arc melting process and emissions problem are less complex. Second, since the average particle size of electric arc emissions is considerably smaller than that of the cupola, different collection objectives exist. Finally, more uniform electric arc operating conditions and lower total emissions tend to simplify the design of control equipment for this process.[1]

(a) Emission Collection Equipment

In 1967, approximately 24 gray iron foundries were reported to have some type of air pollution control equipment for electric arc melting processes,[20] but the number of installations has increased substantially in the last few years.

1. Fabric Filters - Of the major categories of emission collection equipment, fabric filters are best suited for electric arc furnaces and have been most frequently applied. This is due to the extremely fine particle size of dust and fume emitted from electric arc furnaces. Complete installation of a fabric filter unit to the furnace includes ductwork, an exhaust fan to draw gases to the collector and a means of collecting the gases from the furnace.[21] Approximately 20 gray iron foundries reportedly had fabric filter installations on electric arc melting in 1967.[20]

2. Wet Scrubbers and Electrostatic Precipitators - These collection systems are rarely used on electric arc furnaces. Wet scrubber limitations include the existence of too much fine dust and high energy requirements. Electrostatic precipitators can encounter exhaust volumes too low for their design requirements.[5] Four foundries were reported to have wet scrubber installations in 1967 on electric arc melting processes.[20]

(b) Furnace Hoods

Electric arc furnaces are also equipped with various types of hoods to capture emissions.[19] Arrangement of electrodes and gear above the furnace top as well as the charging and operating method largely determines the hood type applied. Often, some type of hood is used in conjunction with an emissions collection system.

1. Full Roof Hood - This type of hood is attached to the top ring of the furnace. It requires stiffening to prevent sagging at high temperatures and protection of electrodes to

prevent short-circuiting.

2. Side Draft Hood - Another design often employed is the side hood. This unit is located on the side of the roof close to the electrodes to produce a lateral type of control. An overhead hood at the charging door is also often used with the side hood.

3. Canopy Hood - Canopy hoods are located above the craneway, and do not interfere with furnace operating procedure. Effectiveness of these units is limited though, due to equipment requirements needed to handle the large volumes of infiltrated air.[21]

(c) Other Methods

1. Fourth Hole Ventilation - In this system, a water-cooled probe is directly connected to the furnace roof. The probe maintains a carefully controlled draft in the furnace body.

2. Snorkel - This technique is similar to the fourth hole ventilation method except that the extra hole serves as a natural pressure relief opening for the furnace.[1]

Electric Induction Melting

Very little attention has been directed toward control of emissions from electric induction melting furnaces. Since no combustion and only limited metal oxidation occur in this type of furnace and because relatively clean scrap is used for charge material, no serious emissions problem exists for induction melting of iron. Induction furnaces normally operate with a heel of liquid metal, and for this reason, metal scrap must be dry and free of oil. Gas fueled dryers and preheaters have been used to achieve this condition, often with operating cost benefits resulting from the use of the lower cost fuel to preheat the charge. The burning of oil residue on the scrap produces objectionable emissions requiring the use of emission control equipment. Afterburners and wet scrubbers, either separately or in combination, are often used to reduce these emissions to acceptable levels. With oil and other combustibles removed from the furnace charge, emission control equipment is not required on induction melting furnaces to satisfy current codes.

Other Types of Melting

The other principal type of furnace used for melting of duplexing of iron is the stationary or rotating, fuel fired, reverberatory furnace. The stationary furnace, often referred to as the air furnace, was once universally used for duplexing when producing malleable iron. Its use has declined with the increase in production of ductile iron, but it is still found in malleable iron foundries. The emissions from this type of furnace come principally from the combustion of coal oil or gas fuel, plus some slag and iron oxide which is carried up the stack with the products of combustion. The older installations all exhausted into the atmosphere through a stack or chimney. Medium energy wet scrubbers and fabric filter bag collectors have been applied in a few cases.

The rotary reverberatory furnace has been only recently utilized in small installations in iron foundries. Since a small quantity of emission in the form of waste products of combustion and slag particles is given off, these installations are not equipped with collectors.

Inoculation

(a) Ductile Iron Production

Original installations for producing ductile iron by magnesium treatment either exhausted directly into the foundry building, or were equipped with a ventilation hood which then exhausted into the atmosphere. In recent years, these stations have been equipped with collecting hoods, or have been installed in enclosed rooms, and the resultant gas is drawn off by means of an exhaust fan, into a dust collection unit. Medium energy wet scrubbers and fabric filter baghouses have been used for emission collection in this area.

(b) Mechanical Property Improvement by Inoculation

Since inoculation in this area produces no major emissions problem, emission control techniques have not been applied.

Mold Pouring, Cooling and Shakeout

Control of emissions resulting from pouring and cooling of molds has been common for several decades for those high volume production foundry installations where finished molds are set out on continuous car-type mold conveyors, providing fixed locations for pouring, cooling, and shakeout operations. With this type of equipment, side draft hoods are often provided for the pouring area and side or bottom draft hoods at the shakeout, with the mold cooling conveyor between these two points fully hooded with sheet metal. Ducting is commonly provided from each area to a single control device, usually a wet scrubber or dry centrifugal collector.

Collection systems have been, and still are, uncommon for those smaller production and jobbing foundries where completed molds are set out on the foundry floor or on gravity roller conveyors, and where the pouring and cooling utilize a substantial percentage of the molding floor. The problem for this type of operation is related more to the cost of capture of the emissions with a minimum amount of infiltrated air, than to separation of the emission. With pouring and cooling in non-fixed locations, without hoods to capture emissions, a large part of the air in the foundry would require handling. The cost would be prohibitive due to the volume to be processed. A partial solution to the problem in the pouring area of non-ferrous foundries has been provided by a traveling vent attached to the pouring ladle bail, and ducted by means of flexible tubing and specially designed connecting ducts to a suitable emission control unit. This technique permits capture of emissions resulting from mold pouring with a minimum of infiltrated air. It is possible that similar methods could be used in iron foundries.

Additional venting is required during subsequent cooling, however, and this is not practical when the ladle is moved on to pour the next mold, with the result that significant emissions are still not collected.

Large castings, such as automotive dies and machine beds, can be cast by the full mold process. Generally, no central pouring station is provided and the smoke generated is released directly into the foundry building, creating an in-plant problem.

The current method for controlling the smoke is through the use of ventilating fans. A properly designed arrangement of fans and makeup air systems may produce a relatively clear shop environment, but as the emissions are exhausted from the foundry, an air pollution problem is created. The problem is further complicated by the fact that ventilating fans exhaust large volumes of air and are not designed to be connected to a duct and collector arrangement.

Sand Preparation and Handling

Processes such as mechanical sand handling systems and sand mixing or reconditioning produce emissions that have received attention over the years. Since most gray iron foundries make green sand molds that produce moisture when the mold is poured, medium energy wet collectors are best suited for effluent control. Occasionally, cotton or wool fabric filters are employed only when dry sand conditions exist. Also, medium energy dry centrifugal collectors are sometimes used. Often, some type of hood is used to capture emissions in sand conveyor systems especially at transfer points. As with many other processes, ductwork and an exhaust fan are required in a complete collection system.[5]

Cleaning and Finishing

The various cleaning and finishing operations produce a significant emissions problem that has received considerable attention regarding control.

Dusts from gate and riser removal are generally controlled with local exhaust systems connected to dry centrifugal collectors, medium energy wet collectors, or possibly fabric filters. Sometimes exhaust hoods are provided above the work station. Other cleaning processes such as abrasive shotblasting and tumbling are commonly controlled with fabric filters or medium energy wet collectors. Applications of dry centrifugal collectors are also made for abrasive cleaning processes.

Most of the trimming and finishing operations generate emissions and require control. Chipping and grinding operations are normally provided with local exhaust hoods connected to either high efficiency centrifugals or fabric filters. Wet collectors are used if central sluicing systems are employed or where grinding exhaust is combined with other cleaning room operations.

Surface painting requires ventilation to reduce the hazard due to volatile materials being atomized in the air. Exhaust systems are generally used where dip painting is performed. Open tank installations are also provided with local ventilation hoods.[5]

Heat treating furnaces for malleableizing or for other treatments of iron castings present the usual problem of emissions from combustion of liquid or solid fuels except where electric or gas fired radiant tube heating is concerned. In most foundries, these are exhausted into the foundry building, or through a stack to the atmosphere. Medium energy wet scrubbers are an effective means of cleaning coal burning exhaust gases, but have not been applied in many cases.

Coremaking

Efforts have been made to control certain coremaking emissions, but the gases emitted from bake ovens and shell core machines are a serious problem difficult to control. Usually these gases are permitted to exhaust to the atmosphere through a ventilation system. Sometimes, catalytic combustion devices are used on core ovens to burn gases to noncombustible analysis.

Other coremaking processes present a less serious air pollution problem capable of control. In coreblowing or coreshooting, fabric filters are usually selected if control equipment is desired. In rare instances, medium energy wet collectors are used. For core grinding, fabric filters and medium energy dry mechanical collectors and wet scrubbers are frequently selected.[5]

Miscellaneous Areas

Finally, emission control equipment is applied in certain non-manufacturing areas in foundries including pattern shops and crating or boxing for shipping, where woodworking operations occur. Dry centrifugal collectors are commonly used to collect wood dust and chips from these operations. Machine shops and metal pattern shops usually present problems of collecting dust from machining or grinding of cast iron. Dry centrifugal collectors are commonly used for this purpose.

CASE HISTORIES OF ATTEMPTS TO CONTROL EMISSIONS IN IRON FOUNDRIES

Although there were individual attempts to eliminate or control foundry emissions before World War II, the serious efforts at emission control started about 1945. Initial efforts concentrated on removal of undesirable dust and fume from inside the foundry buildings and from work areas where large quantities of emissions were generated. The principal means of accomplishing this was to simply ventilate the buildings and to exhaust the emissions to the atmosphere. As the problem increased in severity, many foundries began to apply existing designs of dust collection equipment to individual emissions producers in the foundry. Gradually, the designs of dust collectors began to be directed toward the individual foundry requirements, and the present types of equipment began to evolve.

The history of the development of foundry emission control has been traced from actual case histories which were obtained from reports of public agencies, data from equipment manufacturers, published articles, and private sources.

Because of the differences in the historical development of emission control equipment for various foundry processes over the years, the discussion is divided into two sections: (a) melting processes and (b) non-melting processes.

Melting Processes

Prior to the 1940's, emission control techniques for the cupola, which was the principal melting practice employed at the time, essentially consisted of screen cage spark and dust arrestors or chain barriers. The screen cages, placed on top of cupolas, were simple and inexpensive designs, primarily used for reducing the emission of cinders that caused damage to foundry roofs, gutters and downspouts and which were also a nuisance to the immediate area. Some cinders were removed, but since screen cages were coarse to prevent excessive resistance to gas flow, this technique did little in catching the fine dust also emitted. Chains suspended from weather caps located near the top of the cupola were even less effective.[21, 23]

One of the first emission control equipment systems employed on cupolas and the most widely used in the 1940's was a wet cap. These collectors came into prominence because they were simple, economical systems and a major improvement over screen cages and chains in reducing cupola emissions that led to roof damage and neighborhood nuisance problems.

Success in controlling cupola emissions with early wet cap designs varied widely. Some foundries fabricated their own wet caps while others bought commercially available units. Some foundries experienced increased cleaning efficiency with larger amounts of water. Others were less successful and had excessive corrosion and prohibitive maintenance costs when water usage was increased in efforts to obtain higher cleaning efficiencies. Furthermore, a successful wet cap design for one cupola installation did not always produce similar results on another cupola having the same outward size and characteristics, due to the many variables in cupola operating conditions and the wide range of solids emitted.[21]

Although the first reported installation in the United States occurred in 1938 on a midwestern automotive foundry,[24] wide use of wet caps actually appear to be an outgrowth of blackout efforts in England during the early part of World War II.[5] Another reported installation occurred in 1941, but shutdown of the foundry because of the war prevented testing the wet cap system.[25] Many of the initial wet cap installations which occurred in the early 1940's consisted of a shell and one to three spray nozzles located near the top of the shell.

The first wet cap installation where effectiveness of the gas cleaning system was reported occurred in 1945. Six cupolas at a midwestern automotive foundry were each equipped with a double-cone wet cap system consisting of 70 water spray nozzles. Although no quantitiative test data were revealed, the installation was considered successful from the standpoint of reduced emissions deposited on adjacent roofs and grounds.[24]

Because of the success of the automotive foundry wet cap installation in 1945, the exact same wet cap design was employed on six new cupolas at a gray iron foundry located in the Midwest in 1947. On the first day of operation, the blast on one cupola was turned on before the pump supplying water to the collector could be started. This caused the cone of the scrubber to become thoroughly heated, and when water entered between the cones, the pressure pulled one of the stays out of the lower cone, forcing a stream of water down into the cupola stack. Water to the collector was not cut off for fear of damage, so the bottom on the cupola was dropped and the operation discontinued.

Due to this unfortunate experience, the hollow cone multispray wet cap was discarded. The difficulties with the multisprays were attributed mainly to dirt, pipe scale and boiler scale in the mill water. Maintenance cost was also considered prohibitive.

Later, the original wet cap design was remodeled by removing the upper cone and multiple nozzle arrangement and installing a single large nozzle over the apex of the remaining lower cone. Tests made on the cupolas with the remodeled wet caps showed that .09 to .13 grains per cubic foot of particulates were collected. The resulting emission levels were lower than that experienced by many other foundries with wet cap installations.

An analysis of particle sizes was made as a further check on the performance of these wet caps, and it was found that about 1% by weight of the escaping particulate matter exceeded 40 microns in diameter. Of the remaining 99% by weight, over 99% of the particles, by count, were less than 5 microns.[24]

Wet cap designs introduced in the mid-1940's, such as those consisting of a steel cone, nozzles discharging water in a curtain and a deflector ring, were an improvement over the shell design and are basically the same as current concepts.

In the late 1930's, attempts were made to design other wet-type cupola gas cleaning systems to prevent disgruntled neighbors from bringing suits for property damage. One such attempt occurred at a New England gray iron foundry in 1937. Gases from two capped cupolas were drawn downward through ductwork by a fan to the collector. The heavy particles sank downward by gravity and some of the lighter particles were removed when passed through a water spray. It was reported that 125 pounds of particulates per hour, consisting of coke particles, iron oxide particles, and silicious material, were removed from the gas stream.[26]

During the late 1930's and 1940's, various dry centrifugal collector designs were also used on cupolas but less frequently than wet caps. Some attention was directed in this area, however, because of the advantage of gravity and centrifugal forces in these systems. Particles too heavy to be supported by the upward velocity of the waste gas settled back into the stack, or into expansion-type dry collection chambers. Fine dust collection was poor, and overall collection efficiencies of these dry centrifugal systems were in the range experienced with wet caps.

Dry centrifugal systems used during this period included cyclones, impact chambers, zigzag baffle arrangements and down-up expansion chambers. Problems with high temperature, corrosion and handling the collected dust prevented more widespread use of dry mechanical or centrifugal collectors on cupolas at that time.[23]

Dry centrifugal cleaning principles proved to be more effective when combined with a wet cap system. A combination dry centrifugal, wet cap system installed on eight cupolas in a midwestern automotive foundry in 1948 was reported to be approximately 90% efficient. This system type consisted of a flame suppressor that introduced an atomized mixture of water and air into the rising gases. Then a combination cyclone-type blower unit, conical cap and water sprays further wetted dust particles and washed them down into discharge pipes.[27]

During the early 1940's, systems to control electric arc furnace emissions made use of building roof monitors, roof fans and exhaust hoods. These techniques helped reduce fumes in the plant by exhausting them to the atmosphere but no dust collection was achieved.[5]

In the mid-1940's, foundries began to apply emission control equipment to electric arc melting processes as the following case describes. A roof-type ventilating system was installed above an electric arc furnace in a midwestern steel foundry in the 1940's. During warm weather, the system worked adequately, but gases and dust collected in the building during cold weather and made working conditions unpleasant. In an attempt to overcome this problem, foundry management installed a wet centrifugal unit with a cyclone precleaner in 1945. In 1950, oxygen began to be used in the melting practice and this increased contamination during injection. When the local smoke code could not be met due to this contamination, a battery of spray nozzles was added to the precleaner. This modification reduced dust in the airstream, but wind carried the contaminated water over nearby homes, causing a nuisance. A water eliminator was then added to the system and it was reported that complaints stopped.[28]

During the middle and late 1940's, further improvements in cupola emission control involved use of afterburners in the cupola stack to reduce the visible black plume from unburned volatiles, largely oil from scrap. Also, gas or electric igniters were frequently substituted for traditional wood fire for bed coke ignition. The burning wood often produced an objectionable pungent odor and smoke from partial combustion of the residuals.[5]

Until the late 1940's, very few foundries had any effective type of dust collection equipment system for control of melting emissions. The systems that had been installed, mostly wet caps, were largely due to aroused public opinion of residents located near foundries. In the late 1940's though, the dramatic air pollution difficulties at Donora, Pennsylvania, the adoption of the Los Angeles Air Pollution Control District Code, increased neighborhood complaints, publication of the American Society of Mechanical Engineers smoke regulation and ordinance model, and other factors prompted development of additional emission control equipment and refinement of existing techniques. This was the first major concerted effort to develop high efficiency emissions control equipment.

Efforts to meet the strict Los Angeles County code with wet caps and other designs previously employed during the 1940's proved unsuccessful. The foundry industry and control equipment manufacturers were not aware that cupola emissions contained a large percentage of particles too small to be effectively collected by the equipment in current use. After many tests, it was determined that the fabric filter was best suited to meet the code provisions for foundry emissions. Fabric filters had been used successfully for many years in other industries, but this was the first application to foundry melting processes.

The dramatic increase in collection efficiency that could be experienced with fabric filters is demonstrated by the report on a cupola installation in Los Angeles in 1952. Close to 100% of all dust was collected with a fabric filter consisting of orlon bags.[15]

However, only rare applications were made subseqently of fabric filters with orlon bags due to temperature limitations. Since orlon usually could not be used as a filter material when temperatures exceeded 275° F and because cupola gas temperatures are much higher, attention focused on other filter material that could withstand higher temperatures, such as fiber glass fabric.

Pressure on the foundry industry by the Los Angeles Air Pollution District resulted in the development and use of glass fabric for cupola gas cleaning in the late 1940's and early 1950's. Typical early installations consisted of relatively crude designs where 15-foot-long, 11-1/2-inch-diameter tubes were suspended to a mechanism that was manually operated to "rock" the tubes during shutdown. Production of glass cloth with a silicone lubricant permitted this mild flexing action without rupture of the glass fibers. However, problems with bag wear and the sensitivity of glass fabric to flexing encouraged development of fabric collectors of the reverse flow concept in the early 1950's. This provided more effective dust removal and continuous operation of the collector. However, visible plumes emitting from the foundry stack still presented a problem.[5]

Experimental tests on electrostatic precipitators in the late 1940's were successful in the Los Angeles area and the system was in use in other industries, but attempts to apply precipitators to cupolas were unsuccessful at the time due to maintenance and other problems.

Meanwhile, intensified interest in melting emissions control also had effects on electric arc furnaces which were being installed in increasing numbers during the 1950's. The full roof hood concept that was used in the mid-1940's was modified to that of a local side hood which improved control of electric arc emissions. Fabric filters also began to be used for higher collection efficiencies.[5]

Nationally, there was a reluctance to follow the glass fabric practice of Los Angeles for cupola emission control, especially in the colder northern climates.[5] The multiple dry centrifugal was introduced for such systems in the mid-1950's and tests conducted in 1956 at a Wisconsin foundry equipped with this type collector resulted in efficiencies ranging from 59% to 84%.[29]

Some attention was directed toward other dry centrifugal designs also, such as high efficiency cyclones. Tests conducted on this system type in the early 1950's produced cleaning efficiencies of 65% to 83%.[30] Generally speaking, less success was achieved with high efficiency cyclones than multiple dry centrifugals and this latter type was used on cupolas more frequently when mechanical systems were selected. Dry centrifugal collector design concepts in use during the early 1950's for cupolas are basically the same as current concepts.

In the late 1940's and early 1950's, considerable attention continued to focus on wet cleaning systems for emission control. Even though a number of these systems could not meet the strict Los Angeles code, continued refinements, such as capping the cupola to confine the gases and prevent combustion in the stack, and development of more complex control techniques increased cleaning capabilities. For example, in 1949, a Los Angeles foundry was able to meet existing codes with a cleaning system involving a charging bell, dry centrifugal and wet scrubber.[26]

In other sections of the country, many foundries were continuing to use wet caps, but performance was generally below that obtained by foundries meeting the strict Los Angeles code. A northern foundry, in 1951, installed a wet cap and the major benefit was the reduction in deterioration of the foundry building roof. Complaints from housewives stopped also, but some problems were experienced with the pump because of the acidic condition in the water system.[31]

In the mid- and late 1950's, continued public demand for better cleaning efficiencies prompted development of medium energy wet scrubbers. These systems were more successful than the lower energy wet caps, but not as effective in dust removal as fabric filters. An installation of this type on a 96-inch cupola in the early 1960's produced dust outlet loadings of .035 grains per standard cubic foot which was well below existing code levels.[32]

Development of medium energy wet scrubbers also led to applications on electric arc furnaces where efficiencies of approximately 75%-85% for solid particles were achieved. Problems experienced with these systems included little altering of discharge appearance because of the large percentage of submicron dust and corrosion from oil scrap.[5]

Even though dust collection efficiency was increasing with the development of new systems, complaints still persisted for removal of the visible plumes from cupolas. This encouraged application of the high energy wet scrubber. Although used in other industries since the early 1950's, it appears that the first cupola installations were put in service by an automotive foundry in the mid-1960's, using below charge door gas take-off. At least one installation of that time period condensed the water vapor ahead of the exhaust fan to provide for a smaller fan and drive motor and, at the same time, eliminated the dense steam plume.[5]

Actual results that could be achieved with this system type were demonstrated by a high energy venturi scrubber installation in an Indiana foundry in 1967. Emissions were controlled to about .1 pounds/1,000 pounds of gas or .05 grains per standard cubic foot.[33]

In another example, a medium energy flooded bed wet scrubber tested early in 1969 showed that New Jersey air pollution codes probably could not be met. The results of 5 tests averaged 274 pounds/hour of emissions whereas code standards allowed 205 pounds/hour. The problem cited was that the cupola was not functioning according to design operating conditions.[34] In an effort to correct the problem, the collector was upgraded to a high energy unit in August, 1969. Collector modifications made were:

- Addition of a high energy fume agglomerating section in the original scrubber housing.
- Provision for the use of 15 to 20 GPM liquor per 1,000 CFM of gas.
- Installation of a new fan impeller.

Tests made after the modifications indicated emission levels of approximately 125 pounds/hour--well below the existing code.[35]

In the 1960's, foundries continued installing wet caps because of their simple, inexpensive design and collection capabilities regarding larger dust particles. Replies to a survey conducted by the American Foundrymen's Society, which was documented in 1967, indicated that some foundries were satisfied with performance of their wet caps while others were not. Most of these wet caps were installed to prevent nuisance or damage to the immediate plant property.[1]

Some foundries that previously installed wet caps modified their cleaning systems when local codes became more strict. For example, management of a large midwestern production foundry was faced with a problem of reducing emissions from its 2 60-inch hot blast cupolas that were already equipped with wet caps. In 1968, a variable annulus scrubber was added to the system which, when tested, resulted in an emission level of .12 grains/standard cubic feet (.23 pounds dust/1,000 pounds gas). The wet caps were provided with high efficiency non-clogging multiple flight nozzles and corrosion resistant deflectors to augment the peripheral water curtain. The modified collection system increased previous efficiency levels by 50% in terms of weight of solids collected.[36]

Fabric filters were also often applied on cupolas during the 1960's. Many of these were on the West Coast where codes were strict. This system was an improvement over initial designs, and glass bag material, because of its higher temperature resistivity, was the usual selection. Reports from two California foundries and one in the Midwest, that installed fabric filters in the 1960's, indicated collection efficiencies of over 98%. One of these cases cited high maintenance costs due to bag replacement, but another reported maintenance costs to be low.[19, 37, 38]

Replies to questionnaires distributed by the American Foundrymen's Society, and documented in 1967, indicated that foundry management felt fabric filter performance was good. One case was reported where bags could not be kept in repair because of seam splitting and the foundry intended to replace the fabric collector with a wet scrubber.[1]

Renewed interest developed in the 1960's regarding electrostatic precipitators for cupola emission control. One report on a California foundry, documented in 1967, indicated collection efficiencies of 96.6%.[5] Another installation though, on a large automotive foundry in the Midwest, proved to be unsatisfactory and was eventually discontinued. High maintenance costs were cited in this latter case study.[22] Until recently, because of high costs, maintenance problems, and operating problems, electrostatic precipitators were rarely used to control cupola emissions. Two precipitators have been installed in the last 18 months. The most recent installation is reportedly operating satisfactorily. No maintenance cost data are available because of their short operating history.

Some attention was directed toward use of a dry multiple cyclone collector on cupolas in the 1960's. Replies to the American Foundrymen's Society questionnaire indicated that foundries were obtaining efficiencies from 61%-75% with such equipment. These were results from five tests on different installations.[1]

Current trends appear to indicate that high energy wet scrubbers and fabric filters are the types of emission control equipment systems usually selected for cupolas because of their high efficiency and success in meeting existing codes.

Even though present wet cap designs do not appear to satisfy most air pollution codes, these systems are still being purchased by foundries.

In the 1960's, increasing fabric filter installations were also made on electric arc furnaces. An example of such an installation pertained to an eastern railway signal foundry in the early 1960's. The electric furnace in this foundry melted about 3 tons per hour and was equipped with an exhaust hood that had a 24-inch-diameter telescoping and swivel connection to provide constant ventilation throughout melting and tapping. The dust collector was equipped with approximately 4,800 square feet of orlon filter cloth which provides a 1.7 to 1 air to cloth ratio. To safeguard the orlon bags, a bypass damper was installed in the exhaust piping at the collector inlet. Although no exact collection figures were made available, dust and fumes were no longer considered a problem.[39]

The American Foundrymen's Society survey disclosed that fabric filters did a very good job of emission control for electric arc furnaces. In one foundry, dust collected per ton of charge was 8.8 pounds when scrap was handled manually. After a magnet crane was installed to handle scrap, the dust collected per ton of charge was 13.4 pounds. When scrap was handled manually, much of the dirt would fall to the ground and accumulate, while with the magnet, the dirt would enter the furnace and exit as dust. Complaints concerning these fabric filter installations included:

- Dry dust disposal.
- Bag failure.
- Dust buildup on the clean air side of bag.

- Dust sticking to the side of collection hoppers.

Finally, the survey disclosed that a roof-mounted hood with baghouse was preferred to a roof tap and baghouse system.[1]

Because of the problems with controlling cupola emissions and other factors, some foundries turned to other melting processes, such as electric induction. This trend began in the early 1960's and it was the general belief that induction furnaces offered relief from air pollution legislation pressures. At this writing, no control equipment installations have been reported on foundry induction furnaces. A series of tests conducted at an East Coast foundry in 1968 indicated that coreless induction melting and a charge preheater could be operated in most installations without pollution control devices and yet comply with existing or pending emission limits.[40]

Non-Melting Processes

Contrary to the many developments and refinements in melting emission control equipment systems during the past 25 to 30 years, emission control of non-melting processes such as shakeout, sand handling, cleaning, finishing, coremaking and pattern shopwork is substantially the same now from a technology standpoint as in the mid-1940's. Practically all of the major emission control problems in these areas had been resolved by World War II except for a few improvements which were made in later years. This appears to have occurred for a number of reasons.

First, emission control of non-melting processes has proven to be more economical and less complicated. Also, these processes, when compared to melting, do not contribute as much on an individual basis to the foundry emissions problem. Consequently, less attention has recently been directed toward non-melting processes regarding emission abatement. Reports regarding past attempts to control emissions in these areas are limited in comparison to the widespread interest in solving melting air pollution problems.

Foundry cleaning room operations were among the earliest non-melting processes where attempts were made to control or capture emissions. Prior to the 1930's, sand blast rooms and tumbling mills were in extensive use and local exhaust systems removed the dust, quantities of burned sand, scale and spent abrasive. This produced a number of advantages. First, visibility for the blast room operator was improved and also, since the fractured dust fines were removed, better cleaning efficiency of the abrasive was possible. In addition, a shorter tumbling mill cleaning cycle was obtained by preventing accumulations of dislodged dust from cushioning the impact forces of the tumbling barrel stars. However, it was recognized by some foundries that discharge of such quantities of dust to the atmosphere without collection equipment would cause a neighborhood nuisance.

The hollow trunion design of early tumbling mills made dust collection feasible and dry mechanical, low energy cyclones as well as fabric filters were used for this purpose. Fabric filters were probably more frequently applied and early designs were crude, usually made of wood. Dust collection was fairly good but there were problems with cloth vibration, dust escaping between the fabric and the support and also filter media replacement.

Prior to the 1930's, local exhaust systems were used for various grinding processes especially where sand grinding was employed. Dust particles torn from the cast metal surfaces by the grinding wheels were relatively large and low energy cyclones or fabric filters were used during this early period. Fabric filters were often employed when a single system was used to exhaust grinders and abrasive cleaning or tumbling mill operations. Fabric filter emission cleaning efficiency was fairly good but the use of cyclones was marginal. Although there were no visible particulates in the cleaned air from the collector, oxidation of the settled material discolored buildings and walkways in the area. When higher efficiency cyclones were introduced, this became less of a problem.

The introduction of mechanical sand handling systems and central shakeout equipment in the larger foundries in the early 1930's made dust control through local exhaust ventilation feasible. Dust was released in great quantities in specific locations as compared to the more general release in smaller foundries where floor molding was usually employed. As long as the sand was dry, dust could be collected with fabric filters. However, dry sand required baked sand molds or the storage of the poured flask in an outdoor storage yard for cooling. Most gray iron castings were, and still are, made in a green sand mold and shaken out of the flask as the hot casting has solidified. Under these conditions, steam in quantities was released by the hot, moist sand. This moisture, picked up by the exhaust air heated by the hot castings and sand, made application of fabric filters impractical for most gray iron foundry shakeout and sand systems. Moisture would condense on the filter surface and combine with the sand fines to prevent an effective flow of exhaust air. This condition was dealt with in latter years when wet scrubbers were introduced.

Early foundry wood pattern shops used exhaust systems and later low energy dry mechanical cyclones for dust collection. Since particle sizes from sawdust, wood chips and slivers are large, and also because low velocities are required, collection was good and no significant problems existed. Through the years, cyclones continued to be used and are the usual selection today for woodworking processes.

Fabric filters have also been employed over the years in woodworking areas, often as a final cleaner when cleaned air is returned to the work space during the heating season.[5]

The introduction of wet scrubbers in the mid-1930's improved dust collection capabilities in most non-melting areas including cleaning, grinding, shakeout and sand handling. This was especially significant in shakeout and sand handling processes where wet sand created dust collection problems. A midwestern malleable iron foundry that installed a wet dynamic precipitator reported a collection efficiency of 99% in 1937. This test occurred on a shakeout operation handling four large castings per minute.[41] Another foundry reported a 98% collection efficiency on a sand mixing process with a wet dynamic precipitator. This test occurred in the late 1930's on the East Coast with a collector rated at 5,400 cubic feet per minute.[41] In a cleaning room application, a wet dynamic precipitator was reported to have collected 99% of the dust emitted from a tumbling mill operation. This occurred in 1939 at a foundry located in Tennessee.[41] Successful application of wet scrubbers during the mid- and late 1930's stimulated substantial product development although by the mid-1940's, designs had stabilized along the lines of current four-inch to seven-inch pressure loss collectors.

Early cleaning room practices underwent changes that had a favorable impact on dust collection capabilities in this area. Tumbling mills were rapidly replaced by airless blasting in the 1930's. Also, sand as an abrasive was replaced by grit or shot, originally chilled cast iron but currently cast steel pellets. Metal abrasive created less dust from shattered abrasive fines and had a higher cleaning efficiency than sand. This became increasingly significant when airless blast equipment was introduced. The abrasive development was a major stimulant toward automatic cleaning devices which by the late 1940's had largely replaced the manually directed hose in a sand blast room, except for large or occasional parts, and the tumbling mills. Most abrasive cleaning units, such as tumbling mills, were originally discharged to fabric filters, but when four-inch to seven-inch pressure loss wet collectors were developed, these systems were frequently used. The wet collectors had advantages especially in the larger production foundries where central sluicing systems were in use.[5]

By the late 1940's and early 1950's, advances in wet collector designs made collection efficiencies of 97% or higher typical for sand handling systems. These systems consisted of conveyors, elevators, screens, lines and mixers. From 150 to 500 pounds of dust per hour were collected.

Over the years, many non-melting processes were equipped with various types of hoods to prevent emissions from discharging into the plant. Often, they were used in conjunction with a dust collector. Enclosing hoods and side hoods are two types used in shakeout processes and these have demonstrated a 97% and 90% efficiency respectively. This was reported in the early 1950's.[42]

Reports in the early 1950's on the use of dry centrifugal collectors on metal grinding processes indicated that particulates were reduced to .002 grains per cubic foot. These processes were usually two-wheel grinding stands and collectors captured approximately 15 pounds of cast iron dust per hour.[42]

In the early 1950's, medium energy wet scrubbers and fabric filters were the usual installation on grit blast and airless blast abrasive cleaning processes. Particulates were reduced to approximately .02 grains per cubic foot which resulted in approximately 800 pounds of dust being captured per hour.[42]

As pressures on industry to increase air pollution efforts persisted in the 1950's and early 1960's, foundries stepped up application of emission control techniques to non-melting processes. More attention began to be directed to such areas as mold lines, coremaking, scrap preparation and magnesium treatment for ductile iron production.

In the mid-1960's, mechanically energized wet collectors were installed in a production gray iron foundry in an attempt to improve mold line ventilation. Outlet samples obtained yielded dust loading results that were considered lower than usually achieved in a relatively uncontaminated factory atmosphere.[43]

One large foundry had suffered extensive damage when the core ovens exploded due to exhaust stacks becoming plugged with organic residues. A centrifugal spray collector was installed with facilities for adding chemicals to react with the organic airborne residues. It was reported in 1965 that the stack hazard was eliminated and the combustible and polymerized resins removed.[44]

Another example of coremaking fume control pertains to the experience of a midwestern foundry. In this case, a catalytic combustion system was installed to complete oxidation of contaminants that had been giving off objectionable odors. Complaints that had been raised by nearby residents ceased after the system was installed.[45]

In preparing scrap for melting, centrifuges were often used to reduce excess oil. Driers or kilns were applied also by a number of foundries to drive off moisture and burn off oil from scrap before processing. Furthermore, abrasive cleaning equipment was used to remove burned sand from foundry returns. This reduced dust loss in transferring these returns between different points in the foundry.[5]

A West Coast foundry reported in the late 1960's that plant conditions improved and emissions were reduced as a result of a fabric filter installation on a ductile iron magnesium treatment station. Less emissions were captured when ductile iron was not being produced. This system was also controlling desulphurization.[5]

Efforts continued to be directed in the 1960's toward control of heavy dust producing areas such as cleaning, finishing, grinding and shakeout.

A centrifugal spray collector controlled outlet loadings in a cleaning department to .003 grains/standard cubic feet. This result was obtained by an outside testing laboratory in the mid-1960's in a high production gray iron foundry.[43]

An orifice wet scrubbing collector was installed in the grinding and cleaning area of a midwestern foundry in the mid-1960's. The dirty air was drawn via suction pipes from points near each piece of equipment. The breathing area around each grinder was reported to be substantially dust free and workers did not require masks. Much of the exhaust piping formerly employed at each grinding station continued to be used, but required alteration.[46]

A large midwestern automotive foundry recently reduced emissions in their finishing department to .05 grains per standard cubic foot. Wet collectors, centrally located on the plant roof, achieved this performance. The central location was reported to permit ease of maintenance and repair.[47]

A midwestern foundry recently equipped its shakeout area with an orifice wet scrubber. The collector was mounted on an overhead steel structure that allowed headroom in working areas. Dust was drawn into the collector by two fans and after scrubbing, the sludge deposited onto a conveyor and then dropped into a drum for removal. The collector, rated at 20,000 CFM was reported to have improved operations and working conditions in the plant.[46]

In another shakeout example, tests performed by an independent laboratory showed outlet loadings from a centrifugal spray collector to be .0006 to .0007 grains per standard cubic foot. This test was documented in 1965.[44]

Dust collection equipment also continued to be used in pattern shops. An East Coast foundry, attempting to control dust from woodworking equipment operations, installed a roof-mounted bag collector in the 1960's. Although no quantitative collection figures were available, it was reported that the desired level of air cleanliness was being achieved. Each woodworking machine was equipped with a hood which the dust traveled through before being captured by the collector.[48]

REFERENCES

1. Foundry Air Pollution Control Manual, American Foundrymen's Society, 1967.

2. Cupola Emission Control, translated by P.S. Cowen published by the Gray and Ductile Iron Founders' Society, Inc.

3. "Dust, Fume and Smoke Suppression," A. Grindle, Iron and Steel Engineer, July, 1951, p. 92.

4. Dust Collectors, American Foundrymen's Society, 1967.

5. Personal Notes of John Kane.

6. "Available Control Equipment for the Foundry Cupola and Their Performance, Operations, and System Characteristics," John Kane, presented at American Foundrymen's Society Annual Meeting, May 7, 1956.

7. "Dust Control," R. Whitlock, Ceramic Age, October, 1965.

8. "Foundry Cupola Dust Collection," W. Witheridge, Heating and Ventilating, December, 1949, pp. 70-84.

9. American Air Filter, Rolo-Clone-Type N. Bulletin No. 277E, February, 1967.

10. Pangborn Division, The Carborundum Company, Air Pollution Control by Pangborn.

11. American Air Filter, Reverse Jet Fabric Dust Collector, Bulletin No. 279E.

12. "A Discussion of Some Cupola Dust Collection Systems-Part 3," C. R. Wiedemann, Modern Casting, January, 1970, pp. 72-74.

13. "Choosing Your Electrostatic Precipitator," E.P. Stansny, Power, January, 1960, p. 62.

14. "The Design and Performance of Modern Gas Cleaning Equipment," C. J. Stairmand, Journal of the Institute of Fuel, February, 1956.

15. The Cupola and Its Operation, published by the American Foundrymen's Society, 1965.

16. Introduction to Air Quality Management, Training Course Manual in Air Pollution, U.S. Department of Health, Education and Welfare, pp. 8-10.

17. Air Pollution Manual, published by American Industrial Hygiene Association, 1968.

18. Torit, Dust Collectors, Series 130, January, 1966.

19. Air Pollution Engineering Manual, U.S. Department of Health, Education and Welfare, Public Health Service, Publication No. 999-AP-40, 1967.

20. Private communication.

21. Control of Emissions from Metal Melting Operations, American Foundrymen's Society.

22. Personal notes of James Ewens.

23. "Cupola Dust Collection," W. Witheridge, The Foundry, March, 1950, p. 88.

24. Cupola Gas Scrubbers. O. J. Brechtelsbauer, American Foundrymen, February, 1955, pp. 34-37.

25. "Collectors on Cupolas Clean Waste Gases," O. Allen, The Foundry, November, 1945, p. 89.

26. "Control of Cupola Stack Emissions," J. Drake and T. Kennard, The Iron Age, April, 1949, p. 88.

27. "Around Detroit," O. H. Allen, The Foundry, March, 1949, p. 124.

28. Control Emissions from the Electric Furnace, L. Krueger.

29. American Air Filter, Case History Report, March, 1959.

30. "A Study of Cupola Design and Operating Factors That Influence the Emission Rates from Foundry Cupolas," R. C. Ortgies, reprinted from American Foundrymen's Society Transactions, 1955.

31. Cupola Fly Ash Suppression, R. M. Overstried, pp. 550-551.

32. The Study of the CVX Wet Gas Scrubber in Its Applications on Power Stations, Foundries, and Iron Ore Mills, John Tailor.

33. "Computerized Hot Blast Cupola Serves Induction Holding Furnace in Production of Milton Iron," Industrial Heating, October, 1967.

34. National Dust Collector Corp., Report No. 201, May 19, 1969.

35. National Dust Collector Corp., Report No. 216, September 16, 1969.

36. Foundry Facts, published by the American Coke & Coal Chemicals Institute, No. 5, October, 1968.

37. "Costs, Efficiences and Unsolved Problems of Air Pollution Control Equipment," B. D. Bloomfield, APCA Journal, Vol. 17, No. 1, January, 1967, pp. 28-32.

38. "Capturing Cupola Emissions," Modern Castings, October, 1969, pp. 54-56.

39. "Controlling Dust and Fumes from an Electric Funace," Foundry, September, 1960.

40. "Induction Furnaces, Preheaters and Air Pollution," T. Steffora, Foundry, August, 1968, pp. 82-86.

41. American Air Filter, Roto-Clone Efficiency Studies on Foundry Dust Control, August, 1945.

42. "Foundry Dust Problems and Air Pollution Control," John Kane, Foundry, October, 1952.

43. "Performance Testing Data on Mechanically Energized Spray Wet Type Dust Collectors," R. Jamison, Air Engineering, June, 1965.

44. Performance of Centri-Spray Wet Type Dust and Chemical Fume Collectors, Orlan Arnold, Ajem Labs, June 11, 1965.

45. "Air Pollution Problem Solved," Foundry, no date.

46. "Controlling Foundry Dust," G. Medley, Foundry, June, 1966, pp. 203-204.

47. "A Total Approach," Metal Progress, May, 1969.

48. "Foundry Dust Gets The Air," Iron Age, January 21, 1965.

49. "Cooling Hot Gases," S. A. Reigel and L. Rheinfrank, Jr., Pollution Engineering, November/December, 1970.

VIII - ECONOMIC ANALYSIS OF EMISSION CONTROL TECHNOLOGY

GENERAL

This section deals with the costs of air pollution control systems in the iron foundry industry. Estimates have been made of the capital costs and operating costs of emission control systems, based upon analysis of existing and proposed installations. Additionally, the capital and operating costs of melting departments have been developed for a variety of types and sizes of installations, and the effects of costs of emission control on the overall costs have been determined.

The basic data used in the development of the cost estimates were obtained from the following sources:

1. The in-plant surveys which were conducted as part of this study.
2. Information supplied by selected manufacturers of pollution control and melting equipment. This information was generally in the form of bid figures.
3. Cost information and operating data obtained in the process of developing the foundry data bank.
4. Cost information and operating data from the engineering files of A. T. Kearney & Company, Inc. based on assignments in development of iron foundries.

The cost data obtained are basically for foundries with cupolas controlled with wet caps, mechanical collectors, fabric filters, and high and low energy wet scrubbers, for electric arc furnaces controlled with fabric filters, and for induction furnaces with preheat systems.

CAPITAL COSTS OF CONTROL SYSTEMS

An emission control system was considered to include all items of equipment and their auxiliaries whose sole purpose is to abate atmospheric pollution from a cupola or electric furnace in an iron foundry. The capital costs associated with the estimates included the following cost categories:

- Basic Equipment
- Auxiliary Equipment
- Engineering Cost
- Installation Cost

The summation of these cost categories for a control system constituted the total investment cost. The cost of land upon which the control system is located has not been included.

The specific items included within each cost category are as follows:

1. Basic Equipment - This cost includes all taxes and shipping charges in addition to the "flange-to-flange" price of the basic equipment.

2. Auxiliary Equipment - The cost for auxiliary equipment includes the cost of all items essential to the successful operation of a control system. This category has been further

divided into the following subdivisions:

(a) Air movement equipment costs including:
  - Fans and blowers.
  - Motors, starters, wire, conduit, switches, and other electrical components.
  - Hoods, ductwork, gaskets, and dampers.

(b) Liquid movement equipment costs including:
  - Pumps.
  - Motors, starters, wire, conduit, switches, and other electrical components.
  - Piping and valves.
  - Settling tanks.

(c) Storage and disposal equipment costs including.
  - Dust storage hoppers.
  - Sludge pits.
  - Draglines, trackway, and roadway.

(d) Support construction costs including:
  - Structural steelwork.
  - Foundation, and piers.
  - Insulation.
  - Vibration and antiwear materials.
  - Protective cover.

(e) Instrumentation costs including the measurement and control of:
  - Air and liquid flow.
  - Temperature and pressure.
  - Operation and capacity.

- Power.
- Opacity of the flue gas (smoke meters, etc.).

3. Engineering Cost - This cost allocates the research and engineering expenditures required for the selection of the specific control system, including such items as:
   - (a) Material specification.
   - (b) Gas stream measurements.
   - (c) Pilot operations.

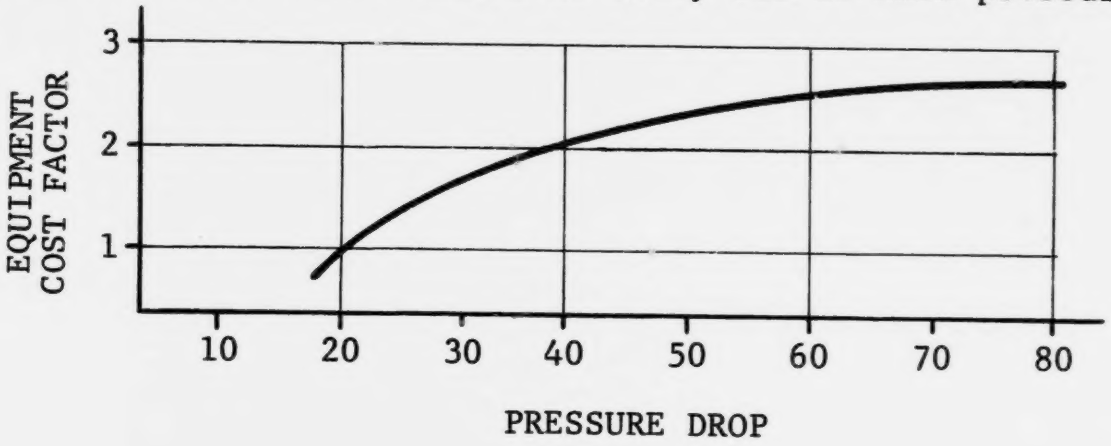
4. Installation Cost - This cost includes the following items when applicable:
   - (a) Labor to install.
   - (b) Site preparation.
   - (c) Building modification.
   - (d) Design contingency.
   - (e) Field office charges including supervision and engineering.
   - (f) Inspection.
   - (g) Protection of existing facilities.
   - (h) System start-up.
   - (i) Profit reduction attributable to plant shutdown for installation.

Exclusive of the value of the land the equipment is located on, the summation of the foregoing items represents the total investment required to purchase and erect the pollution control equipment, connect it to the furnace, and bring it into operation. This total investment cost is the figure used in analyzing capital costs of installations.

The different installations for which capital cost data were obtained represent systems whose ages range from the present to 20 or more years. To compensate for differences in installation dates, investment costs were converted to a common base of 1969 dollars. This adjustment was made by using the material, construction, and labor indices published by Engineering News-Record, March, 1970.

The basic and auxiliary equipment costs are the main components of the total capital cost. These equipment costs varied on the average from 42% to 66% of the total capital cost.

The collection equipment costs for wet scrubbers (limited to the collector, exhauster and motor) varied more widely as a function of pressure drop. These component prices are affected by the energy required. Increases in pressure drop for example, result in larger horsepower needs which are reflected in greater investment costs in the motor, starter, and all other electrical components. In the following chart, the relative variation is shown. The reference index is unity for 20-inch pressure drop.



The curve illustrates that the cost of the basic control equipment is more than twice as great for a 40-inch pressure drop system than for a 20-inch pressure drop. The relative change from 40-inch to 80-inch is about 20%. In addition to the basic control equipment cost increase, there will be increases in the necessary appurtenances such as electrical starters, wiring, controls, etc. Not included in the above curve are the costs for water clarification, quencher, engineering, cupola caps, and erection.

The total equipment costs for scrubbers represent on the average about 65% of the total investment costs. Erection costs are about 35% of the total cost and approximately 54% of the total equipment price.

The overall impact of the basic equipment costs (collector, exhauster, and motor) on the total investment cost is less significant and well within the shaded range of the investment cost curves discussed later. The impact of the range in pressure drops does, however, affect operating costs, due in part to higher electrical energy requirements. This will be further covered in the discussion on operating costs.

The following information illustrates the average ratios and ranges observed for cupola installations.

Equipment Costs as a Percentage of Total Investment Cost

Control System	Equipment Cost/Total Investment Average	Equipment Cost/Total Investment Range
Wet Caps	42%	36% - 67%
Mechanical Collectors	55%	36% - 79%
Low Energy Wet Scrubbers	65%	48% - 80%
High Energy Wet Scrubber	66%	48% - 85%
Fabric Filter	65%	41% - 82%

The ratio of equipment to total investment varies considerably on an individual foundry basis. The wide variance in the range of equipment cost as a percent of total investment is caused by several factors. The data represent installations at many foundries which have many different requirements. Some foundries had available space for the control equipment while others required some plant modifications to install the equipment. The age of the foundry affects the cost. In some new foundries, the pollution control equipment was designed as an integral part of the facility, while in old foundries, additional costs must be incurred for adaptation of facilities.

These factors and others, as reviewed in Exhibit VIII-1, represent unique differences between one foundry and another. The differences affect the total investment cost, as represented by the ranges given in the previous table.

The major factor that influences capital cost is the type of melting equipment. The complexity of control systems is greatest for the cupola, moderate for the electric arc, and least for induction melting.

Cupola Melting

Air pollution capital costs are most varied for this method of melting, and control solutions encompass a wide variety of collector designs. Often, the collector type will determine the required system components. Separate studies were made of each of the four major control methods. The factors that have the greatest influence on the investment costs include those listed as follows:

1. Number of Cupolas Served on a Single System.
2. Materials of Construction - Corrosion is a major problem in cleaning cupola gases by wet methods. Temperature is another major factor. Service factors influence the selection of materials of construction. Investment costs will vary significantly when the unit is constructed of corrosion-resistant metals such as stainless steel or when the ductwork is refractory lined.
3. Water Supply and Solids Disposal - Investment increases for wet systems when drain water is clarified in a separate settling tank, chemically treated, and recirculated by pumps back to the collector. These costs are obviously less for systems using dry collection methods.
4. Erection Costs - Costs vary greatly with prevailing labor rates. In addition, the location of the control system, whether on a new or existing site, plant arrangement, and special rigging required, will affect costs.

Electric Arc Melting

A typical air pollution control system for this method of melting consists of a local exhaust hood on, or at, the furnace roof, duct connections from the hood to the collector, and a fabric filter collector. The factors which influence the major components of an electric arc control installation include the following:

1. Exhaust Hood - The exhaust hood will vary with the diameter of the furnace. Also influencing costs are the problems of attaching or supporting the hood to the furnace structure and the ease of providing a suitable fixed exhaust point that will permit the furnace roof and hood to swing for charging and tilt for slagging and pouring.

2. Duct Connections - The cost of ducts will vary with the size of the ducts, which are a function of exhaust volumes, the length of duct run and the amount of interference encountered.

3. Dust Collector - These costs are essentially a function of exhaust volume. The cost of power supply for collector motors depends upon the collector location and the plant power system.

4. Installation - Erection costs vary with prevailing labor rates, and problems of adapting to existing conditions.

Factors which contribute to cost variations are summarized in Exhibit VIII-1.

RELATION OF CAPITAL COSTS OF CONTROL SYSTEMS TO DESIGN VARIABLES

A number of design and operating variables are related to the total cost of emission control systems. These include melt rate of the furnace, pressure drop of the system, blast volume in standard CFM and gas volume throughput in actual CFM. A computerized multiple regression analysis of the collected data has confirmed that total costs varied most directly with actual gas volume throughput.

The greatest differentiation in capital costs due to outlet dust loading existed with wet scrubbers, for low energy systems, under 30-inch static pressure drop, and high energy systems, over 30-inch static pressure drop. The costs of these two categories have been considered separately.

Cupola Melting

The total investment costs of high and low energy wet scrubbers, mechanical collectors, and fabric filters vary directly with gas volume throughput in actual cubic feet per minute. Investment cost equations were obtained by multiple regression analysis, in which the equations obtained were the best approximation of total investment costs from the available data. The investment cost equations for pollution control equipment installed on cupolas are presented in Exhibit VIII-2. The column in Exhibit VIII-2 entitled "Limits of Observation" gives the ranges of gas volumes for which each equation is valid.

As shown in this exhibit, excellent correlations were obtained with high energy wet scrubbers and fabric filters. A perfect correlation coefficient is 1.0. Although the correlation coefficients for low energy wet scrubbers and mechanical collectors were lower, they were considered to be extremely good. Graphs of each equation are plotted in Exhibits VIII-3 through VIII-5. The range shown on each graph represents the standard deviation of the statistical analysis.

The total investment curves all relate total investment costs in 1969 dollars to gas volume throughput. Gas volume throughput is related to cupola operating conditions and furnace design. The significant factors which influence gas volume in a cupola are the following:

- Blast volume.
- Size of charging door.
- Method of cooling exhausted gases.
- Location of exhaust gas take-off.
- Gas temperature at the collector and its exhauster.

Blast volume is a function of the oxygen needed to burn the coke. Metal to coke ratios can be increased to produce higher melt rates by preheating the blast air, by oxygen enrichment of the blast air, and by the use of a supplemental fuel. However, in present-day practice with an open charging door and with gas take-off above the door, the variation in blast volume caused by these factors will become a less significant factor in the total gas throughput handled by the control system than the amount of infiltrated air drawn in through the charging door.

Charging door openings require an inward flow of air to confine cupola gases and contaminants. Many designers of air pollution abatement equipment specify an indraft based upon 300 FPM through the door opening, which results in significant additional exhaust volumes that must be handled by the exhauster and collector. Even such volumes are subject to wide variations where charge door openings are exposed to aspirating crosswinds. Charge door openings are determined by the method of charging and the size of charging equipment, and consequently may have little relation to melting rate. The effect of air infiltration may increase gas volumes to as much as 200% where gas take-off is above the charge door.

Hot gas in the cupola stack must be cooled to safe temperatures for the control equipment and exhauster. The degree of cooling will differ with the type of system but the exhaust gas is normally cooled down to about 500° F for mechanical or glass fabric collectors and below 200° F for wet scrubbers and synthetic fabric collectors. The usual methods of cooling are by water sprays or air cooled ducts. However, cooling of gases by use of water from the high temperatures in the cupola stack introduces another significant gas volume, that of the water vapor generated. Water vapor can increase the total gas volume handled by the control equipment by 20% to 35%.

The location of the gas take-off also contributes to the overall cost of the control system. The placement of the take-off below the charge door reduces the total gas volume handled since indraft air is at a minimum. The cost for control equipment for any given type of control system is also subject to a number of other factors that have less correlation with melting rate than the gas volume.

Exhibits VIII-6 and VIII-7 give the approximate melt rates and gas volumes for lined and unlined cupolas. The increase in gas volume due to a gas take-off above the charge door is quite apparent when compared to a below the charge door take-off. Exhibit VIII-8 presents a single comparison of gas volumes for gas take-offs above the charge door and below the charge door for a lined cupola.

Operating a cupola with an open charge door with an above the door gas take-off results in a greater total gas volume. The cost of the control equipment is then based upon this higher gas volume. Efforts to reduce the total gas volume have been successful in several ways, as described in the following list:

1. Providing doors to partially seal the charge opening except during the charging period.
2. Reducing the charge opening through the use of a vibrating feeder instead of a bottom drop or skip bucket charger.
3. Enclosing the skip hoist to eliminate the wind effect and reduce the net open area.
4. Exhausting the cupola gases from below the charging door level.
5. Using a top charge double door design.

The amount of water vapor in the exhaust gas can be reduced by use of indirect heat exchangers which use the heat in the exhaust gas for heating the blast air. With a below the door take-off, some wet collector systems quench the gases without burning off the CO. This results in exhaust gas temperatures of 400° F-700° F instead of the more usual 1500° F found with afterburning, and also results in a corresponding reduction in the volume of water vapor produced.

The total investment costs can be approximated by first determining the total gas volume generated from Exhibits VIII-6 and VIII-7 and applying this volume to Exhibits VIII-3 through VIII-5 for the cost of the specific system type. However, for ease of interpretation, Exhibits VIII-9 through VIII-14 have been prepared to relate installation costs for high and low energy wet scrubbers and for fabric filters directly to melting rate of cupolas in tons per hour. The melting rates were based on an average metal-coke ratio of 8:1. Wet cap installations are directly related to cupola diameter with relatively little relationship to melting rates or gas flow. Total investment costs for wet caps as a function of cupola size are given in Exhibit VIII-15.

Wet Scrubber Efficiency-Pressure Drop Relationship

The wet scrubber curves have been separated into high energy--over 30-inch pressure drop--and low energy--under 30-inch pressure drop. The relative effectiveness of each is shown in Exhibit VII-21. High energy scrubbers on cupolas are up to six times more effective than low energy systems, with a typical outlet loading of 0.05 gr/SCF for 30-inch to 70-inch pressure drop systems compared to 0.3 gr/SCF for systems under 30-inch pressure drop.

The degree of gas cleaning obtained at various pressure drops is illustrated in Exhibit VII-28. Wet scrubber efficiencies in capturing particles exceeding 1 micron in size are 90% or more for pressure drops of 10 inches and above. At 30-inch pressure drop the efficiency exceeds 99% for particles of 1 micron and larger. However, for fine particle sizes, in the range of 0.2 micron and below, a 30-inch pressure drop system is only 95% efficient.

The overall collection efficiency is determined by the particle size distribution in the effluent gas and the ability to capture these particles. For a constant pressure drop, a scrubber has a different collection efficiency for each particle size. The overall efficiency is the weighted sum of efficiencies for each particle size.

Exhibit VIII-16 has been derived as a theoretical presentation of overall collection efficiencies of wet scrubbers at various pressure drops. This was done for a typical particle size distribution and is based upon data found in the available literature. As shown in the exhibit, the efficiencies in percent of weight collected range from 95.4% at 5-inch pressure drop to 99.8% at 60-inch pressure drop. The results obtained are theoretical and not representative of actual efficiencies which may be obtained at these pressure drops. However, the exhibit does illustrate the trends in increased collection efficiency at increased pressure drops.

Increased collection efficiencies due to higher pressure drops result in a decreased outlet loading. The amount of the outlet loading or discharge is influenced by local air pollution codes. Many codes provide for a maximum allowable discharge.

A plot of the outlet loading versus pressure drop for foundries for which data were available is given in Exhibit VIII-17. The outlet loading is expressed in pounds/ton which factors the melt rate into the total allowable discharge of pounds/hour expressed in process weight tables of many air pollution codes.

This exhibit illustrates the expected increase in pressure drop required to reduce outlet loading. An approximation can easily be made to determine the energy necessary to satisfy the maximum allowable discharge for a foundry for those codes which utilize process weight tables. The Los Angeles County Code, for example, limits the maximum discharge to 10 pounds/hour for a process weight of 10,000 pounds/hour (5 tons/hour). The resulting outlet loading is 2 pounds/ton, and from Exhibit VIII-17 the pressure drop necessary to satisfy this condition is 30 inches.

Electric Arc Melting

Although the electric arc furnace is used in the iron foundry for both melting and for holding, the economic analysis has been directed only at the melting application. The reason for this is that only a few holding furnaces have been equipped with emissions control systems because the level of emissions for holding only is relatively low when compared with melting. The economic analysis was also limited to fabric filter collectors on arc furnaces, again because only a few installations have been made using other methods.

Fabric filter installations on electric arc furnaces have been related to the diameter of the furnace, rather than the tons per hour melted. Exhaust volume and furnace diameter relationships approximate the figures in the table below and in Exhibit VIII-18.

Exhaust Volumes for Electric Arc Furnaces

Roof Diameter	CFM Local Hood	CFM Canopy Hood
6 feet	20,000	55,000
8 feet	26,000	70,000
10 feet	30,000	90,000
12 feet	33,000	115,000
14 feet	36,000	150,000

Fabric filters can be of the intermittently cleaned, single section design, or the compartmented, continuous duty design. When each melting furnace has its own fabric filter, the collector can be stopped and serviced at the end of each melting cycle. For multiple furnaces controlled by a single collector and for large exhaust volumes, the continuous duty design is usual. On this basis, cost estimates could be approximated as shown in the tabulation below.

Approximate Installed Cost, $/ACFM for Electric Arc

	Local Hood		Remote Canopy Hood	
Roof Diameter	Intermittent Operation	Continuous Service	Intermittent Operation	Continuous Service
6 feet	$2.10	$2.50	$1.25	$1.85
8 feet	1.90	2.50	1.25	1.75
10 feet	1.85	2.35	1.25	1.70
12 feet	1.85	2.30	1.25	1.60
14 feet	1.80	2.25	1.25	1.60

Exhibit VIII-19 gives the approximate total installed cost of fabric filter collectors on electric arc furnaces. This cost has been related to furnace size and has also been converted to melting rates usually associated with various furnace diameters.

Other Melting Methods

Induction melting furnaces, as well as induction holding units, have only rarely been equipped with emission control systems. This is also true for reverberatory methods of melting. For this reason, information has been lacking regarding costs of installations on this type of equipment. Therefore, data on costs have not been prepared for this study for these types of installations. However, the cost of induction melting will be discussed in a later section dealing with melting department costs.

OPERATING COSTS OF CONTROL SYSTEMS

A comparison of the impact of operating costs has been made for wet scrubbers and fabric filters. These were the more popular and commonly used types of control systems observed on foundry melting equipment.

The annual operating costs associated with air pollution abatement equipment are comprised of several components, including the following:

- Fixed charges
- Maintenance
- Operating costs
- Water treatment
- Depreciation

Fixed charges are calculated on the basis of total investment cost. A rate of 13% per year has been used to account for interest, insurance and taxes.

Maintenance includes labor costs and routine replacement costs, such as bags in a fabric filter. Maintenance expenditures are not necessarily uniform from year to year and will increase after the passage of time. New equipment may require little or no maintenance but maintenance requirements will generally increase as the system grows older.

Data collected have indicated that an annual expenditure of four to five percent of the original equipment cost for wet scrubbers provides an adequate amount for good maintenance. In the case of fabric filters, the maintenance figure was estimated to be about five percent per annum of the original equipment cost. These percentages were reduced to about two percent for smaller foundries which melted less than 1,000 hours per year, with lower pollution control system utilization.

In addition, a separate amount was added for bag replacement. This was based on a 100% bag replacement each year for foundries with continuous melting and reduced to a 100% bag replacement each third year for foundries with intermittent melting. The replacement cost was $10 per bag. Manufacturers of fabric bags have indicated that in a large number of cases, the replacement of filter bags has been less frequent than once a year, with bags sometimes lasting five years or more.

The number of filter bags required for cupolas and electric arc furnaces with local hoods was calculated for an air to cloth ratio of two to one. For electric arc furnaces with a canopy hood, the air to cloth ratio used was four to one.

The maintenance costs used in the analysis do not include costs associated with equipment modifications after installation. A few foundries visited reported a large expenditure for changes early in the life of the control equipment, and some reported a cost for modifications after several years.

A disproportionate increase in maintenance costs may possibly occur in systems with large pressure drops. The increased horsepower and system requirements due to greater pressure drops may create conditions that accelerate the maintenance costs. This has not been determined for this study.

Operating costs include electrical power and makeup water. For wet scrubbers, these are the major costs. Electrical power is required for the fans and pumps. Power requirements vary with the equipment size and pressure drop. The total power requirements for high and low energy scrubbers are 15 HP/1,000 ACFM and 6 HP/1,000 ACFM respectively. These formed the basis for calculating operating costs for scrubbers. Power requirements for fabric filters were based upon 2 HP/1,000 ACFM.

Requirements for makeup water in gas cooling and scrubbing are related to equipment size. The data collected have indicated a correlation of makeup water to equipment size for wet scrubbers at about 2 gallons/1,000 ACF.

Electrical energy and demand costs were calculated at rates based upon the prevailing power rates in the Midwest for process industries. Water costs were also based upon rates in large midwestern cities. The water cost used in the analysis is $.275/1,000 gallons.

Many foundries utilize afterburners in cupolas to insure the ignition of the top gases. The combustion of the top gases burns off any carbonaceous matter present in the exhaust gases. Other foundries rely on afterburners to specifically burn off carbonaceous material. A review of the capacities of the burners utilized indicates that the selection is somewhat independent of cupola size or melt rate and is rather arbitrary. Several foundries had afterburners of such size and capacity to provide substantially more energy than required for complete combustion. The use of afterburners has not been considered in the total annual costs. However, an approximate cost per operating hour for each million BTU's of gas burned is $.60, based on midwestern gas costs.

Water treatment includes the chemical treatment to the scrubber water in the sludge tank. This includes flocculation and neutralization. Foundries requiring water treatment indicated a range of $.03 to $.085 per ton of iron for chemical costs. For the purpose of this analysis, $.05 per ton was used.

Depreciation was calculated on a straight line method based upon total investment. The useful life of control equipment was taken as 10 years. In several foundries, however, the equipment was found to have a longer service life, but rapid advances in technology and more stringent local codes may tend to accelerate technical obsolescence of these older units.

The annual calculations of cost for wet scrubbers are based upon four levels of foundry operation: 500, 1,000, 2,000 and 4,000 hours/year. It is reported that in large foundries operating 4,000 hours or more per year, rather than shutting down cupolas during "off" shifts and over a weekend, they may be run at a reduced level. This results in additional operating hours for the control equipment, which may cause a slight increase in the cost estimates.

Exhibits VIII-20 and VIII-21 present approximate total annual costs for high and low energy scrubbers on cupolas and are presented for operating levels of 500, 1,000, 2,000 and 4,000 hours/year. The curves relate total dollar costs versus gas volume for a single system pressure drop. As the pressure drop of a control system increases, the power requirements will increase. A doubling of the pressure drop, for example, results in a doubling of the required horsepower.

Exhibit VIII-22 presents the relative change in total annual costs as pressure drop increases. These were calculated for each operating level. It becomes readily apparent from this exhibit how a change in pressure drop affects wet scrubber annual costs.

If pressure drop increases from 30 to 40 inches for a 5-ton-per-hour melt rate and a 500-hour/year operating level, the increase in annual costs would be from an index of 1 to about 1.04 or a 4% rise. The corresponding increase in theoretical removal efficiency, from Exhibit VIII-16, would be a rise of 0.1%. A larger foundry operating at 4,000 hours per year and at 30-ton-per-hour melt rate would experience an annual cost increase of approximately 6% for a pressure drop increase from 40 to 50 inches. The increase removal efficiency for this example would be about 0.1%.

The detailed information to make up Exhibit VIII-22 has been plotted as total annual costs in dollars, versus gas volume for a family of pressure drop curves. This was done for each operating level. These curves are presented in the detail economic cost curves in Appendix D.

In the case of fabric filters, it was assumed that gas cooling is accomplished by air and not by a water quench. This removes the need for makeup water and water treatment. The total annual operating costs for baghouse installations on cupolas are illustrated in Exhibit VIII-23. These costs are presented for 4,000 hours/year, 2,000 hours/year and 1,000 hours/year. The comparable costs for fabric filter installations on electric arc furnaces are given in Exhibit VIII-24 for canopy hood and local hood exhausts. Operating levels of 4,000 hours/year, 2,000 hours/year and 1,000 hours/year are also presented.

RELATION OF OPERATING COSTS OF CONTROL SYSTEMS TO DESIGN VARIABLES

The annual costs of wet scrubbers and fabric filter collectors on cupolas, as presented in Exhibits VIII-20 through VIII-23, are all based on gas volume throughput expressed in ACFM. However, there is a relationship between gas volume and melt rate for different metal to coke ratios. Exhibits VIII-6 and VIII-7 gave this relationship for lined and unlined cupolas.

By combining Exhibits VIII-6 and VIII-7 with Exhibits VIII-20 through VIII-23, the annual cost of wet scrubbers and fabric filters on cupolas are expressed as a function of melt rate for a variety of metal to coke ratios. Also included are comparative costs for gas take-offs above and below the charge door.

The curves of annual cost versus melt rate are presented in Appendix D. Sets of curves are given for operations of 4,000 hours/year, 2,000 hours/year and 1,000 hours/year for low and high energy wet scrubbers on cupolas and for fabric filters on cupolas. Both lined and unlined cupolas are considered.

As expected, installations with gas take-offs above the charge door have higher annual costs than similar control equipment installations but with gas take-offs below the charge door.

The total annual costs for scrubbers and fabric filters on cupolas, as illustrated in Appendix D, have also been modified to present the costs on a basis of cost per ton of melt. Estimates of cost per ton of melt are given in Appendix D for the various operating conditions and operating hours discussed earlier.

A summary of the cost-per-ton curves, comparing 4,000-hour/year, 2,000-hour/year and 1,000-hour/year levels of operation, are given in Exhibits VIII-25 through VIII-30. These summary curves are given for low energy and high energy wet scrubbers and fabric filters on cupolas for a constant metal to coke ratio.

From these exhibits, it becomes apparent that the cost per ton of melt rises rapidly as the size of the foundry operation decreases. The cost increases, for example, for a high energy scrubber from $3/ton at a 4,000-hour year to over $8/ton at a at a 1,000-hour year. Lower levels of operation would exceed $12/ton or more.

EFFECT OF EMISSIONS CONTROL ON CAPITAL AND OPERATING COSTS IN MODEL FOUNDRIES

Model Foundry Development

The effect of adding emission controls, on the capital and the operating costs of the melting department in the iron foundry, was developed for a variety of different melting methods, different sizes of foundry, and different levels of operation. The various alternates which were evaluated are described below.

(a) Melting Systems Studied

1. Cupola melting, cold blast, lined, below door gas take-off, with unheated forehearth, with fabric filter emission control.

2. Cupola melting, hot blast, unlined, water-cooled, below door gas take-off, using channel-type induction holding furnace, with a high energy wet scrubber emission control system on the cupola.

3. Arc furnace melting, using channel-type induction holding furnaces, and provided with a fabric filter emission control system on the arc furnace.

4. Induction furnace melting, crucible type, no holding furnace, using scrap preheaters, and with afterburners provided in the preheater stack for emission control.

(b) Sizes of Foundries Studied

Sizes of foundries in terms of tons per hour melting capacity were selected at levels of 5, 15, 30, and 50. The range included in these melting rates covers most of the foundries operating in this country with the exception of a few very large captive plants and some very small operations.

(c) Levels of Operation Studied

The operating levels included in the study, in terms of hours per year of melting operation, were selected as 500, 1,000, 2,000, and 4,000. These correspond respectively to melting 2 hours per day, 4 hours per day, 8 hours per day, and 16 hours per day.

Because of practical operating limitations on some types of melting equipment, not all melting methods were analyzed at all melt rates and operating levels.

Qualifications Regarding Model Foundry Design Data

The intent of the model foundry economic development in this study was to provide comparative figures relating the capital and operating costs of melting departments of foundries of varying sizes and rates of operation, and utilizing different methods of melting, to the requirements and costs of emission control. The actual design and operating data were based on commonly utilized equipment and raw materials, for the foundry sizes and rates of operation which were selected, and thus represent average conditions rather than actual operating foundry cases. It was recognized that further refinement of these design and operating data would probably result in cost figures which would more closely approximate actual costs in many foundries. However, the figures which were developed are believed to be reasonably representative and are useful for comparative purposes.

Equipment and Building Specifications

The model foundry melting departments which were developed for this economic analysis were intended to represent typical conditions for the methods of melting and the sizes of foundries which were evaluated. For purposes of comparison, similar facilities for auxiliary operations and services were used in each case. The only exception was that the smallest size melting department did not contain a full complement of auxiliary items, in accordance with usual design practice in these small installations.

The melting department was considered to encompass the facilities and operations from raw materials receiving through molten iron holding. This included raw material unloading, scrapyard, charge makeup, charging, melting, scrap preparation, emissions collection, slag handling, water system, holding furnace or forehearth, buildings and services.

(a) Melting Equipment

The melting systems covered were those in principal use: cold blast, lined cupola; hot blast, unlined water-cooled cupola; electric arc furnace; and coreless induction furnace. Channel induction holding furnaces were used for the water-cooled cupola and the electric arc installations, unheated forehearth was used for the lined cupola, and no holding furnace was used for the induction furnaces. High energy wet scrubbers were applied to unlined cupolas, fabric filters to the arc furnaces, and a minimum afterburning system on the scrap preheater for the induction furnaces. An alternate of fabric filter collectors was also considered for the lined cupolas.

(b) Emission Control Equipment

Emission control equipment selected was based on those items normally used to control emissions for a particular melting method and includes basic as well as auxiliary equipment.

Melting alternate No. 2 is equipped with a wet scrubber emission control system. A wet scrubber's capability to capture particulate matter is a function of the amount of energy expended in the system which is measured by pressure drop. The higher the pressure drop, the greater the amount of particulate matter collected and the higher the capital and operating cost for the system.

Wet scrubber designs were selected that would satisfy the more stringent air pollution codes. For the purpose of this study, the air pollution code for Los Angeles County was selected as a basis for determining wet scrubber efficiency cost requirements.

The Los Angeles Code establishes a maximum allowable discharge per hour based upon process rates.[1] Exhibit VIII-17 indicates the minimum pressure drop required to capture various emission discharge levels. From this information, it is possible to determine the pressure drops required to satisfy the Los Angeles Code according to melting rates established for this study. These figures are shown below:

Melt Rate, Ton/Hour	5	15	30	50
L.A. Code Maximum Discharge (pounds/hour)	10	22.22	40	40
Outlet Loading (pounds/ton)	2	1.48	1.33	.8
Wet Scrubber Pressure Drop Required to Meet L.A. Code	30 in.	40 in.	45 in.	60 in.

Melting alternate Nos. 1 and 3 are equipped with fabric filters. Since fabric filters collect nearly 100% of all particulates and therefore meet existing air pollution codes in analysis of their relative capabilities and efficiencies for this investigation was not required. The only point that needs clarification is that the fabric filters selected for the arc furnaces are equipped with a local hood rather than a canopy type.

(c) Buildings

A determination was made of the appropriate amount of building space which would be required to melt iron based on the five alternates selected. This included provision for all auxiliary building requirements such as transformers and similar equipment. No provision was made for cost of land.

Capital Costs

This consists of all melting, holding, auxiliary equipment and buildings as well as emission control systems required for a typical melting department.

Melting and holding equipment capital costs are current figures obtained from equipment suppliers and data from foundry installations. Costs of equipment installations including foundations and services, such as engineering, have been based on percentages of original new equipment cost. Building costs per square foot are based on midwestern construction figures and vary according to the type of melting method employed. Emission control equipment capital costs were obtained from information previously developed which is shown in Exhibits VIII-3, VIII-4, VIII-18 and VIII-19.

Exhibit VIII-31 summarizes capital costs required to install melting departments for the various alternate melting methods and foundry sizes which were considered. The details of these capital costs are given in estimates in Appendix D. That portion of total capital costs accounted for by emission control ranges from 0.5% to 19.4% depending on the production and operating conditions involved. More specifically, these ratios vary by the conditions defined as shown in the table.

	Percent of Emission Control Cost to Total Capital Costs					
Alternate Number	Lowest	Melt Rate Tons/Hour	Operating Hours	Highest	Melt Rate Tons/Hour	Operating Hours
1	11.6%	5	2,000	19.4%	50	2,000 4,000
2	12.1%	15	2,000 4,000	16.3%	50	2,000 4,000
3	5.9%	50	2,000 4,000	12.7%	5	500 1,000 2,000
4	0.5%	30 50	2,000 4,000	0.6%	5 15	500 1,000 2,000 4,000

Operating Costs

These costs were developed per ton of hot metal at the spout of the melting or holding furnace and include direct materials, all conversion costs and emission control equipment operating costs related to the various methods established.

Exhibit VIII-32 gives a summary of total operating costs per ton required to produce iron based on the alternates under investigation. These figures are briefly summarized in the table on the following page.

Melting Costs - Per Ton of Iron

	Melt Rate Tons/Hour	5				15			30		50	
Alternate Number	Operating Hours per Year	500	1,000	2,000	4,000	1,000	2,000	4,000	2,000	4,000	2,000	4,000
1		$127	$102	$ 90	-	$ 88	$79	$72	$75	$69	$71	$66
2				89	$79		76	68	71	65	68	62
3		211	142	106	-	125	96	80	89	76	84	73
4		182	128	101	-	98	82	74	80	71	76	69

(a) Direct Material Costs

The metal to be produced was selected as gray cast iron having 35,000 PSI tensile strength which is a grade commonly produced. To provide a meaningful comparison, all alternatives were studied on the same basis. The direct materials used for the various melting furnaces were selected as representative charge proportions which would provide the desired grade of iron. Prices of direct materials are based on published quoted prices for the second quarter of 1970, Chicago area. For both the cold blast and hot blast cupola melting methods, a metal to coke ratio of 8 to 1 has been used in the study. The direct material costs per ton for the five melting methods are shown in the table below.

Melting Method	Direct Materials $/Ton
Lined Cupola - Cold Blast	$51.09
Unlined Cupola - Hot Blast	47.14
Electric Arc	44.69
Induction Coreless Type	47.06

These direct material costs have been applied to all melting rates and all production levels studied. No attempt was made to evaluate the effect on scrap prices of volume buying by the larger foundries which would operate 2,000 or 4,000 hours per year. Also, the type of casting being produced affects the yield and the available percentage of casting returns. Approximately one-third of the metallics were assumed to be returns.

The details of the direct material proportions and per ton costs are shown in Appendix D.

(b) Conversion Costs

Conversion costs consist of all direct and indirect labor, supervision, supplies, maintenance, depreciation, capital charges, utilities and allocated expense required for charge makeup, charging, scrap handling and preparation if required, melting and holding. Allocated expense consists of that portion of other foundry functions such as general management, quality control and administration which are necessary to operate a foundry melting department.

Conversion costs, calculated for each of the alternatives, were based on operating data obtained from foundries. The data were modified as required to fit the particular operating condition.

Conversion costs per ton for the various conditions investigated are shown in the table on the following page.

Conversion Costs - Per Ton of Iron

Alternate Number	Melt Rate Tons/Hour	5				15			30		50	
	Operating Hours/Year	500	1,000	2,000	4,000	1,000	2,000	4,000	2,000	4,000	2,000	4,000
1		$ 66	$45	$35	-	$33	$26	$20	$22	$16	$19	$14
2		-	-	38	$29	-	27	19	22	16	19	14
3		144	85	55	-	75	48	33	41	29	37	27
4		144	86	56	-	57	38	28	34	25	30	22

Conversion cost details are shown in Appendix D.

(c) Emission Control Costs

This consists of all costs associated with operating an emission control system and includes capital charges, maintenance, utilities and depreciation.

Emission control operating costs were derived from data previously developed which are depicted in Exhibits VIII-20, VIII-23 and VIII-24.

1. Alternative costs. Emission control equipment operating costs per ton for the different conditions investigated are shown in the table.

Alternate Number	Melt Rate Tons/Hour	5				15			30		50	
	Operating Hours/Year	500	1,000	2,000	4,000	1,000	2,000	4,000	2,000	4,000	2,000	4,000
1		$10.00	$ 6.00	$3.50		$4.00	$2.33	$1.33	$2.33	$1.33	$1.80	$1.00
2				3.50	$2.50		2.00	1.25	1.83	1.17	1.65	.98
3		22.40	12.40	6.50		5.47	3.27	2.13	2.45	1.60	1.96	1.28
4		.46	.27	.17		.20	.14	.11	.12	.10	.11	.09

That portion of total operating costs accounted for by emission control ranges from 0.1% to 10.6% depending on the alternative condition. More specifically, these ratios vary by the conditions established as shown in the table below.

	Percent of Emission Control Cost to Total Operating Costs					
Alternate Number	Lowest	Melt Rate Tons/Hour	Operating Hours	Highest	Melt Rate Tons/Hour	Operating Hours
1	1.5%	50	4,000	7.9%	5	500
2	1.6%	50	4,000	3.9%	5	2,000
3	1.8%	50	4,000	10.6%	5	500
4	0.1%	50	2,000 4,000	0.3%	5	500

2. Wet scrubber costs and efficiencies. To properly evaluate wet scrubber performance for this investigation, it is necessary to determine the relationship between costs, efficiencies and pressure drops. As mentioned previously, the Los Angles County Air Pollution Code formed the basis for wet scrubber requirements.

Exhibit VIII-16 indicates theoretical wet scrubber particulate removal efficiencies and corresponding pressure drops for a typical particle size distribution. Based on these figures, the efficiencies developed are presented below:

Melt Rate Tons/Hour	5	15	30	50
Pressure Drop	30	40	45	60
Particulate Removal Efficiency	96.5%	98.9%	99.5%	99.8%

An increase in the pressure drop for each melt rate would result in an increase in removal efficiency. This condition would also increase wet scrubber operating cost as shown in Exhibit VIII-22. In developing Exhibit VIII-22, a pressure drop of 30 inches was selected as an index. Curves are given for each of the four operating levels; i.e., 500, 1,000, 2,000 and 4,000 hours per year.

As shown in Exhibit VIII-22, a pressure drop increase from 30 to 40 inches would result in an increase in the wet scrubber annual costs index from 1.0 to 1.05 for the 2,000-hour-per-year operating condition. This represents a cost increase of 5%. Therefore, the 5-ton, 2,000-hour wet scrubber operating cost previously shown would increase from \$3.50 to \$3.71 if a 40-inch, instead of a 30-inch, pressure drop scrubber was selected.

Summary of Capital and Operating Costs

Exhibits VIII-33 through VIII-36 depict the relationships of capital costs to operating costs per ton for the various production and operating conditions investigated. These figures were obtained from Exhibits VIII-31 and VIII-32.

BENEFITS OF EMISSION CONTROL INSTALLATIONS

The major emphasis of this chapter has been directed toward estimating the costs associated with purchasing, erecting, and operating emission control equipment. In this section, the direct and indirect benefits to the foundry for installing emission control equipment are discussed.

During the field interviews for obtaining data, foundries were asked to identify any benefits they had experienced from controlling air pollution. In a vast majority of the cases the installations were new, and it was too early for the foundry to ascertain if any benefits would accrue. Several of these foundries expressed an anticipated savings in roof maintenance due to less frequent cleaning.

Roof maintenanace and gutter cleaning was the most frequent benefit listed. The reduction in particulate emissions also resulted in less frequent cleanup in other areas of the plant. Maintenance and building deterioration were reduced, resulting in less cleaning and painting. One foundry reduced the cleanup required at the air intakes, heater coils, and ductwork.

Many foundries expressed a direct savings in plant maintenance costs. The reported savings ranged from $600 to $5,000 per year. A large foundry, producing 30,000 tons per month, indicated a savings in equipment and building maintenance as great as $200,000 per year. The manpower requirements for maintenance were reduced. Where one man was required constantly at one foundry without control equipment, the installation of pollution control equipment reduced the manpower needs for pollution-related maintenance to one man every four weeks.

Other foundries indicated a general improvement in the in-plant environment due to the elimination of cupola gases escaping at the charge door and dispersing through the plant. The atmosphere on the charging floor has become clearer and the generally cleaner foundry atmosphere resulted in better light conditions. As a result of the generally healthier working conditions, employee relations were improved. Several foundries indicated that as a by-product of the cleaner foundry environment, employee complaints and personnel turnover have been reduced. One large foundry reportedly experienced a savings of as much as $200,000 per year due to fewer personnel problems.

Most foundries located close to residential and commercial areas stated that with control equipment, atmospheric conditions in the neighborhood improved to degrees that neighbors' complaints virtually ceased.

Other benefits attributed to the installation of control equipment were that potential hazardous areas of toxic gases were eliminated and refractory replacement in cupola stacks were reduced.

Although no sound economic use of the particulate matter has been stated, many foundries use the by-product for land fill.

REFERENCES

1. County of Los Angeles, California, Air Pollution Control District, Rules and Regulations, Regulation IV, Prohibitions.

IX - TECHNICAL AND ECONOMIC ANALYSIS OF POTENTIAL MODIFICATIONS TO FOUNDRY PROCESSES AND EQUIPMENT

IMPROVEMENT OF EMISSIONS CONTROL CAPABILITY

Three approaches are possible in the effort to improve foundry emissions capability at a lower cost: the modification of emissions producing equipment to reduce emissions, changes in operating practice, and improvement of emissions control equipment. Modification of emissions producing equipment often requires a change in operating practice. Because of this condition, potential changes in these two areas are discussed together, and improvements of collecting equipment are discussed separately.

A systems concept must be applied to the analysis, particularly with regard to costs. An increase in scrap metal cost, for example, resulting from a change in quality specifications, or special pretreatment, may have an overall cost benefit if a less costly control device can be used to collect the emissions.

An overview of industry efforts toward this basic problem shows no major technological breakthrough, but rather an ongoing effort to better existing equipment through improved design and the use of new materials.

Some results of innovative thinking are apparent such as the reverse draft, "upside-down cupola," and a cupola emissions cooling system using a counterflow of a granular material such as sand. The successful operation of these particular systems has not yet been proven, although a full-size test of the new cupola design is now under way with published results expected in the near future.

Due to the proprietary and often confidential nature of research and development effort by equipment manufacturers, detailed information on various projects under way at this time cannot be discussed unless public disclosure has already been made. The material in this section is therefore limited to recent developments not yet fully accepted by the industry, or to concepts advanced by industry representatives outside the equipment manufacturing companies.

POTENTIAL MODIFICATIONS TO FOUNDRY PRACTICES AND EMISSIONS PRODUCING EQUIPMENT

Of all foundry operations causing emissions to be released to the atmosphere in some degree, the melting operation has received the greatest attention from emissions control boards, the general public, foundry operators, and equipment manufacturers.

The effort to improve collection capability at a lower cost has been concentrated on the problem of the cupola as the source of the greatest amount of particulate matter. The result of these investigations in recent years has been a number of modifications offering at least a partial solution to the problem.

Other work has been done in the areas of preheating, magnesium treatment for producing ductile iron, pouring and cooling, sand handling and coremaking.

Potential Modifications to Cupolas and Cupola Operations

Cupolas and cupola operations can be modified in an attempt to achieve two goals--to decrease the cost of emissions collection and to decrease the quantity of emissions requiring collection. With collection equipment and operating costs directly related to the amount of gas to be processed, a direct approach to the cost problem is to decrease the gas volumes. A regression analysis, described in Section VI, showed no significant relationship between cupola design factors and emission quantities. The analysis did, however, indicate that emission would be lessened by modifications to operating practices resulting in decreasing the coke charge and eliminating contaminants from the charge material.

(a) Decrease Stack Gas Volume

One method of decreasing the volume of cupola stack gas is to limit air infiltration by reduction of the charging door area. This requires a change in the charging equipment since a large door opening is required for the entrance of drop bottom, core bottom, and end or side dump charging buckets. In place of buckets, the charge materials can be discharged into the cupola by chute or oscillating conveyor. Some concern over possible charge segregation was expressed when this modification was first proposed, but evidence from several systems now in operation shows that the problem is not serious with the lighter density charges in general use at this time. Cupolas up to 48 inches in diameter have been charged successfully by means of a chute, and cupolas up to 84 inches in diameter by means of an oscillating conveyor, using a standard skip hoist to raise the charge materials from the yard level.

One foundry has recently installed a new water-cooled cupola with the charging opening reduced from a normal 96 square feet in area to 16 square feet. Charging equipment consists of a conventional skip hoist, and a 42 inch wide vibrating feeder. The feeder is arranged so that it can be moved forward into the charge door opening for charging and retracted when the material is completely discharged into the cupola. Reduction of the door opening has reduced the inspirated air 83% and total gas volume 59%.

A cost comparison of systems using conventional and conveyor charging methods was prepared to aid in final selection of equipment. The analysis included equipment and operating cost estimates for the two systems furnished with emission control equipment to limit emissions to 0.15 and 0.05 grains per standard cubic foot of exhaust gas. The comparison shows equipment cost savings of approximately $80,000 using the small charging door and conveyor charging. Annual operating cost savings are about $7,500 for the 0.15 gr/scf system, and $18,500 for the .05 gr/scf system using the small charging door opening. The system is reported as working satisfactorily with no adverse effects due to charge distribution or segregation.

Locating the gas take-off below the top of the charge burden is a second method of reducing air infiltration and thereby decreasing the volume of gas to be cleaned. This method requires the use of an induced draft fan to substitute for the stack effect and is used on cupolas with emission control equipment. Placing the take-off approximately 3 feet below the top of the charge effectively limits air pulled down through the burden to about 10% of the blast air volume, independent of the charging door area.

There are two alternative methods of processing the gas after removal from the cupola. In one, the gas passes through a combustion chamber where secondary combustion occurs with the assistance of a gas burner and with only sufficient air added to support the combustion. Combustibles including carbon monoxide are completely burned, after which the gas is cooled, cleaned, and discharged to the atmosphere. For the other alternative, the gas is immediately cooled, cleaned, and discharged back into the cupola stack below the level of the charging door, where it can be ignited by afterburners to remove the carbon monoxide content, if desired. A portion of the cleaned gas, which contains essentially no oxygen, is drawn into the gas take-off and recycled through the flooded disc scrubber. A certain hazard exists in cooling the gas after take-off prior to immediate ignition in a combustion chamber. The negative pressure in the take-off enhances the possibility of inward air leakage through any opening, and also of drawing air downward through the burden, to form an explosive mixture of CO and O_2. Discharge of the cleaned and cooled gas into the cupola below the charging door insures against inspiration of air through the charging door, but extra care must be taken to insure that the take-off ductwork is airtight when installed. A good preventive maintenance program is desirable to insure that it remain so.

Reduction of charging door size with conveyor or chute charging and below charge door gas take-off systems are effective in reducing the quantity of infiltrated air. However, they lend themselves more readily to new installations than to modifications of existing cupola melting systems. The expense of relocating an existing skip loader or charging machine and possibly altering or installing a charging floor for the feeder usually offsets the operating cost savings. Only if the existing cupola is charged by crane or monorail is it probably economically feasible. Installation of a below charge door take-off on an existing cupola can also be too costly to result in an early payback. Lack of space adjacent to the existing cupola may not permit installation of a combustion chamber or cooling device to quickly lower the gas temperature to a safe level.

One manufacturer of emissions control equipment has recently reported on a system with the gas take-off located opposite the charging door opening. The total gas volume, including inspirated air, is reportedly reduced about 50% by the special design of the take-off. The infiltrated air sweeping across the cupola stack from the door opening to the gas take-off acts as an air curtain preventing escape of the off-gases out the open charging door or vertically into the upper stack. This system, if technically successful, has the advantage of requiring relatively simple and inexpensive alterations to an existing cupola. The gas take-off should be somewhat less expensive at the charging door level than near the top of the cupola since it will be smaller and require less supporting structure than at the higher elevation. Furthermore, the resulting gas volume requiring cleaning is independent of charge door area and whether the charge door opening and cupola top are open or closed.

A fourth technique for reducing air infiltration is providing doors for the charging inlet. This method has been in use for some years with indifferent results, due to mechanical and electrical problems with door operating controls, and with warping and lining problems with the doors themselves. Severe operating conditions have inhibited the development of reliable mechanisms for opening and closing the doors at the desired times. Furthermore, sudden increases in gas volumes when the doors are opened either overload the collection system, or require that it be designed for the full open door capacity. The result of the first is puffs of incompletely cleaned gases and of the second, no savings in the system cost.

The problems related to charging doors have resulted in the discontinuance of many installations after repeated damage to the doors by charging buckets. The most successful and long-lived have been those installations with the simplest of mechanical controls. In order to permit sufficient air infiltration for secondary combustion, doors are either provided with openings in the bottom half, or are made shorter than the cupola door opening. Installation costs ranging from $1,500 to $3,500 per cupola have been reported depending upon the cupola size and type of operating mechanism and control.

(b) Decrease Coke Charge

Reduction of coke in cupola charges offers some beneficial results. The evaluation of cupola emissions, described in Section VI, indicates that particulate emissions tend to decrease as the amount of coke in the cupola charge decreases. In addition, the replacement of the coke with lower cost fuels results in lower melting costs under certain conditions.

Foundry operators contacted in the course of the study expressed considerable dissatisfaction with the increasing cost of coke coupled with a reported decrease in quality. In several cases a distinct credibility gap exists with regard to proximate analyses submitted by vendors. An experienced cupola operator can quickly judge the coke quality by the furnace operation and, in many cases, his judgment varies substantially from the analysis submitted with each shipment.

Heating of the cupola blast air has been recognized for many years as one method of increasing the melting rate with the same coke charged or of maintaining the melting rate with a smaller coke charge. Use of hot blast for only the latter reason, however, is rarely practiced. The economic benefit of increasing the melting rate with hot blast is too much greater than the more moderate savings obtained by using less coke at the same melting rate. Neither have installations of air heating units been made for the specific purpose of reducing emissions level. Only two hot blast cupolas listed in Exhibit VI-11 are reported as having emissions below the median of 36.5 pounds per ton of melt. All unlined cupolas in the exhibit use warm or hot blast to overcome the greater heat loss from the unlined shell and to increase the melting rate.

Hot blast is universally achieved by means of a fuel fired heat exchanger. Natural gas is readily available in many parts of the country for about $0.06/therm (100,000 BTU) for the medium-sized user. The coke replaced by the gas costs approximately $45.00/ton delivered, representing a cost of $0.155 per 100,000 BTU. The operating cost savings amounts to approximately one dollar per million BTU of heat in the blast air.

Oxygen enrichment of the blast air also results in a decrease in coke requirements by eliminating the 80% nitrogen in air which would otherwise require heating to the iron melting temperature in the cupola. Like blast heating, however, oxygen enrichment is invariably used to increase melting rate by increasing the amount of oxygen available to the coke. An accompanying benefit of the 80% reduction in volume of the oxygen compared to the air it replaces is that specific blast rate as related to melting rate is reduced. The earlier emissions analyses showed the correlation between specific blast rate and emissions rate.

Enrichment of blast air with 4% oxygen has been reported to result in savings up to $1.50 per ton of metal melted by permitting the use of less costly metallics in the charge and by increasing the melting rate up to 25%. Test data quantifying the reduction of particulate emissions resulting from oxygen enrichment are not available. The facts suggest, however, that the installation of such a system only for the purpose of reducing emissions would be uneconomical, if the cupola were operated at the normal melting rate and full advantage were taken of decreased coke charge.

Natural gas injection, like oxygen enrichment, provides a means by which cupola coke requirements can be reduced, melting rate increased, melting costs lowered, and a modest decrease in particulate emissions realized. The major research effort in this field has been briefly described in Section VI. Results of tests 12 and 11 in the research program showed melting rate increases of 37%, melting cost savings of $1.22 and $2.01 per ton, and emissions rates down about 15% when 30% and 40% of the coke was replaced by natural gas. The reported cost savings include only the following unit operating costs:

Coke	$40.00/ton
Natural Gas	0.06/therm (100,000 BTU)
Carbon	0.04/pound
Silicon	0.159/pound

Amortization of the estimated $20,000-$35,000 equipment investment is not included. The discussion in Section VI emphasizes the fact that emissions rates would probably be lowered more if blast air had been reduced approximately in proportion to the decrease in coke charge, but no test data are available for this condition.

(c) Prepartion of Charge Materials

The evaluation of cupola emissions in Section IV points out that many of the emissions can derive from the presence of undesirable materials in the charge. These materials include coke and limestone dust, sand, nonferrous metals, and a variety of combustibles such as oil, grease, and synthetics. These materials can be more or less completely removed from the charge by more effective preparation of the coke, limestone, and metallic scrap, with a resultant decrease in cupola emissions.

Screening of limestone and coke before loading into the charging bucket is an elementary and inexpensive step to prevent breeze and dust from being charged into the cupola. A simple grizzly bar screen for the mechanized foundry, or the use of a fork rather than a shovel in the manual foundry, will suffice. This precaution is commonly taken, but an occasional foundry, large or small, is found where the absence of screening is obvious from the puff of black dust from the top of the cupola as each charge is dumped. The investment is extremely nominal and there is almost no operating cost.

Removal of embedded molding and core sand from foundry returns can be effected with a shotblast machine at an estimated cost of $2.00 to $2.50 per ton. This is infrequently done, however, due to its cost, or the lack of available equipment. A five-minute blast cycle is sufficient to clean the returns.

Other scrap preparation is more often performed by scrap dealers than foundry personnel due to the equipment cost and labor requirements. More and more of today's scrap is automotive, consisting of whole or broken engines or fragmented bodies. Charging of whole engines into cupolas, as a significant number of foundries do, results in emissions problems from the engine oil, grease, nonferrous, and alloying materials from the engine components. Whole engines are available from scrap dealers at a reported cost of $24-$30 per ton. Engines that have been fragmented and stripped of the large majority of nonferrous components reportedly sell for about $50 per ton. Some scrap dealers are equipped to break, wash, and strip engines on continuous lines consisting of a breaker, detergent washing tank and a supporting conveyor system including a picking or sorting conveyor where nonferrous materials are removed. This operation, which removes all oil and grease from the scrap, adds $3.50-$4.00 per ton to the cost of the material.

Cupola scrap as purchased from dealers contains a minimum of nonferrous materials, in large part because these materials command a higher price, and it is to the dealers' interest to separate them out for sale for the larger amount. Nevertheless, a certain amount of copper alloys and even more of the lower value nonferrous metals find their way to the foundry scrapyard. The large mechanized foundry is not generally able to sort out undesirable scrap due to the volume and method of handling employed. On the other hand, the operator of a smaller foundry, particularly one with manual or semi-mechanized charge makeup, can instruct scrapyard personnel to set aside questionable scrap for little additional labor cost.

Another problem, gaining importance with the increased use of automotive scrap, is the inclusion of synthetic fibrous material in shredded steel scrap derived from auto bodies. This material, if not consumed in the furnace or by the afterburners, tends to clog the collection equipment. Except for the possibility of this type of contaminant and its relatively low density, shredded automotive scrap offers an advantage for cupola use in that the analysis is nearly constant, with little nonferrous metallic inclusions. Specifications for this material should limit nonmetallic inclusions, by requiring incineration or other suitable process.

(d) Cupola Design Changes

While minor design changes of conventional cupolas have been shown to have little effect on cupola emissions rates, one newly developed cupola design is so revolutionary as to warrant special mention.

The cupola is top charged through two charging bells roughly similar to a blast furnace. Blast air, preheated to approximately 1100° F, enters the cupola through tuyeres located somewhat below the bottom bell, raising the temperature of the coke to the ignition point. The metal charge is melted in this oxidizing zone and the molten metal along with the products of combustion flow downward through the coke bed in a reducing atmosphere. A portion of the particulate matter in the gas is absorbed by the coke and the molten metal and slag. At the bottom of the cupola, the molten metal, slag and gas flow into an enclosed forehearth where outside air is mixed with the gas and secondary combustion is achieved. At this point, particulate and gaseous combustibles are burned. At the same time, the velocity of the gas stream is sharply decreased as it flows into the forehearth, and additional particulate matter settles out on the slag layer where it is absorbed. The hot gases pass through a recuperative blast air heater and are exhausted to the atmosphere.

The design is currently being tested on a full scale installation. Preliminary test results show emissions levels well below 0.05 grains per standard cubic foot, although some operating problems are still being worked on. No installation or operating cost data have yet been developed.

(e) Change Melting Method

The increase in the number of electric and reverberatory melting furnaces in recent years, at a time when the number of iron foundries have decreased dramatically, is evidence that one acceptable solution to the problem of the high cost of emissions control is to replace the cupola by a furnace that produces less emissions. Installation and melting costs as shown in Section VIII are not always lower, but the total of the advantages sometimes tips the scale in favor of cupola replacement. Exhibits III-5 and III-6 show the population changes in types of melting systems in recent years and projections for the next ten years.

Growth patterns in the population of electric arc and induction furnaces have been well documented. In addition, reported sales of reverberatory furnaces for iron melting are reported to be increasing as the result of the recent clean air laws. Stack sampling test results for a reverberatory furnace without any emissions control equipment melting one ton per hour of gray iron show emissions of 0.82 pounds. This emissions rate is well below current minimums and explains the interest of the smaller foundries in the use of reverberatory furnaces despite problems of superheating the molten iron. This type of furnace in capacities of 500, 1,000, 2,000 and 4,000 pounds per hour are sold completely wired, piped and lined ready for use. Installed costs including shipping charges, hood, stack, skip loader, and reasonable connection costs are estimated to be as follows:

500 pounds/hour	- $15,000
1,000 pounds/hour	- 18,000
2,000 pounds/hour	- 22,500
4,000 pounds/hour	- 28,000

Capacities given are for melting and superheating gray iron to 2750° F. Capacities for melting malleable iron to 2650° F are double those shown. Manufacturers of reverberatory furnaces estimate that sales of these units will total 50-75 in 1970, and that at least this many will also be sold in 1971.

The reverberatory furnaces described above are all batch-type melters. A continuous type of fuel fired furnace has been designed and installed on an experimental basis in an operating foundry. Test data were not available at the date of issue of this report, but the designers were hopeful of achieving the dual benefits of lower cost melting than is possible in the cupola and reduced emissions generation.

Potential Modifications to Other Melting Furnaces

It has been demonstrated that melting emissions from induction and reverberatory furnaces are generally below minimums established by the various control bodies. No modifications to these types of furnaces, for the purpose of reducing emissions, have been reported. Electric melting is a batch process requiring a forehearth or holding furnace to provide the continuous supply of molten metal possible from a cupola. One major manufacturer has reported the development of a continuous melting coreless induction furnace permitting a better basis for comparison with cupola melting. The furnace is "U"-shaped with a horizontal coil located in the center. Preheated charge materials are placed in the charging leg and the molten metal is discharged from the top of the other leg. No decrease in melting emissions results from the new design.

Emissions from electric arc furnaces tabulated in the general foundry data range from 6 to 28 pounds per ton of metal melted. The variation in rate is related to operating practice rather than to details of furnace design. For this reason, no investigations into possible design modifications to reduce emissions are being carried out as far as is known. Clean, uncontaminated scrap will, however, tend to decrease emissions as it does in the cupola. The use of an afterburner to burn combustible materials is particularly beneficial, since fabric filters are almost universally used with arc furnaces.

Modifications to Magnesium Treatment for Producing Ductile Iron

Inoculation of molten iron with some form of magnesium for producing ductile iron is inherently a violent process that is enhanced by the need to provide a strong stirring action for insuring complete mixing of the inoculant with the iron. While the process is basically the same today as when it was first introduced to the industry, much progress has been made in the development of different carriers for the magnesium and methods of introduction of the inoculant into the metal bath to slow the reaction, promote greater retention, and decrease the resulting emissions. Despite these advances the problem is severe, particularly when the process is performed in the open foundry area. Attempts have been made to contain the emissions in order to decrease environmental hazards as well as to lower the cost of capture of the emissions. These have included the use of pressure ladles, pressure chambers, ladle covers with or without connections to an exhaust and collecting system, and enclosed inoculation stations. The pressure systems are relatively expensive and time-consuming. Compared to less costly systems, they can usually be justified only when the pressure is used to improve the effectiveness of the nodularization. Ladle covers at specific inoculation stations have a nominal cost compared to pressure systems. Inoculation station enclosures can be installed for $2,500 or less, complete with ductwork to an existing collector and prevent the magnesium oxide and other fume from blanketing the whole melting, pouring and mold making area.

Modifications to Sand Handling Systems

Foundry molding sand when moist does not produce emissions while being conveyed from the mixer to the molding machines. After pouring, however, the heat absorbed from the molten metal evaporates a large part of the moisture, and sand fines become airborne at the conveyor transfer points. Conventional control for this condition is to enclose these points with hoods and connect all transfers to a dust collector. A new concept of dust control, recently patented, blankets the return sand with moist prepared sand, effectively limiting the dusting normally encountered. The dust eliminating feature of the system is actually an added benefit, since the concept was developed to solve the problem of hot molding sand.

In operation, excess molding sand is mixed and circulated through the system with the overflow from molding requirements discharged onto the return sand conveyor immediately following the shakeout. The ratio of sand prepared to metal poured is in the range of 20 or 30 to 1. Several benefits result from this excess of sand. The heat of the shakeout sand is absorbed by the prepared sand that blankets it, resulting in a very nominal total temperature rise in the total mass. Convection cooling on the conveyor system dissipates most of the heat. Because the proportion of shakeout sand to the total mass is small, only small amounts of additives, such as bonding materials and water, are required, and mulling time can be sharply decreased. Additives are metered to the shakeout sand immediately after the shakeout, and before the overflow prepared sand is discharged on the conveyor. With moist sand forming the top layer on the belt, no dusting occurs, and no dust collection is required except at the shakeout. The decrease in dust collection requirements not only results in lower investment needs, but also lowers operating and maintenance costs, and air makeup and heating costs. Sand storage facilities can be reduced by as much as 80% since the majority of the sand is constantly recirculating and being cooled. Installations have been cited where savings of 50% in investment for the sand storage bin, sand coolers and aerators, and dust collectors have been realized for this process compared to conventional sand systems. Some additional capacity for mullers and conveying equipment may, however, be required which will tend to offset some of the savings. A highly variable cost not included in the above must also be considered. Due to the patents outstanding for this process, royalty payments are required for its installation and use. Molding sand dust control systems for conventional installations located in existing foundries are often extremely costly due to the necessity of fitting ductwork into crowded areas and around obstructions. A cost estimate for an "average" installation of this kind is not possible due to the possible variations for each specific case.

POTENTIAL MODIFICATIONS TO EMISSIONS CONTROL EQUIPMENT

Improvements in emissions control equipment in the foreseeable future, with few exceptions, promise to be minor in nature. These will be results of efforts by the manufacturers of this equipment to improve quality of manufacturing, use of better materials and redesign to raise efficiencies and lower costs of their products. Three modifications have been reported that could be of significant importance: the development of a high temperature metallic fabric for fabric filters, the use of a granular filter bed, and a system of cooling cupola emissions in a rain of sand particles followed by a fabric filter. No economic analysis is possible for these developments since cost data are not yet available.

Patent applications have been reportedly filed for a metallic fabric suitable for use as a dry filter system with a maximum gas temperature approaching 2000° F. Few additional details are available at this time. The reported expanded temperature range would permit installation adjacent to the furnace with little or no gas cooling by water sprays or a convection cooler. The system drastically reduces the danger of destruction by the heat or glowing particles carried over into the filter. In addition, the metallic fabric would be relatively immune from action of hydrofluoric acid resulting from fluorspar additions to the charge. The system is presently in the experimental and pilot model stage and has not been tested in a full scale installation.

A foreign manufacturer of control equipment has developed a control device using a granular material as a filter bed for cleaning furnace gas. The filter bed material is reported to be a nearly spherical natural material with a close diameter tolerance that will clean furnace gas to 0.05 gr/scf. Some systems are reportedly working satisfactorily in Europe. Sales representation in the United States is now supposedly being negotiated. Full disclosure of details is expected within a few months.

Another emissions control device utilizing granular material like sand for cooling cupola gas has recently been announced in this country. The use of sand size material as a heat transfer medium is effective because of the extremely large surface area per unit weight. This patented system uses a rainfall of sand in an enclosed tower through which the cupola emissions rise. The cooled gas is cleaned in a conventional fabric filter, and the heated sand is discharged into a second tower in which fresh air rising in counterflow cools the sand to its original temperature. The cooling air also passes through a fabric filter before being exhausted to the atmosphere. The cooled sand is conveyed to the upper level for reuse. All equipment utilized in the system is standard and has been proven in operation for many years. While sand is abrasive and equipment used for its transport requires regular maintenance, the problems are familiar to foundry personnel and require no special maintenance skills.

IMPACT OF POTENTIAL MODIFICATIONS TO FOUNDRY EQUIPMENT AND PRACTICES

Exhibit IX-1 tabulates ten potential modifications to cupola melting practices or equipment resulting in either decreased cost of emissions collection or lower emissions rate. Operating cost savings are significant for those items that reduce the volumes of stack gas required to be cleaned. The first modification, small charging door and conveyor or chute charging, is reported by cupola manufacturers as gaining wide acceptance, and the majority of recent orders specify this feature. It is often, however, not an economical modification to an existing installation. The second item in the exhibit also is effective but usually it is too costly to adapt an existing cupola to below charge door gas take-off. The "at charge door" take-off, listed third, has not yet been proven from a technical standpoint. Since it can easily be installed on an existing cupola, its success means that any foundry using a cupola for melting can take advantage of one of three economical methods to substantially decrease the cost of collecting cupola emissions.

The second and third categories of modifications listed in Exhibit IX-1 include methods to reduce cupola emissions up to 25%. The modifications to reduce coke requirements offer operating cost savings up to $2.00 per ton of melt but result in only moderate decreases in emissions. Preparation of charge materials to reduce or eliminate certain emissions components results in additional operating costs up to $4.00 per ton of melt. None of these modifications, however successful in reducing specific emissions, will result in the ability to use lower cost collection equipment, since they do not affect the release of all fine metallic oxide particles. Thus, despite the additional cost of up to $6 or $7 per ton, the same high energy systems will be required.

It can therefore be said that it is less costly to provide equipment to collect whatever emissions are produced in a cupola than to control the input of materials causing the emissions, particularly when steps are taken to keep gas volumes to a practicable minimum.

The other practical approach to the problem of the cost and difficulty of collecting cupola emissions is to replace the cupola with a different kind of melting furnace. Foundries of medium size and larger, depending upon local cost and availability of raw materials and fuel, often find electric induction or arc furnaces economically advantageous. The small foundry, and even some medium-sized foundries, for whom electric melting investment requirements are too great, may well find reverberatory furnaces a low cost answer to the problem. Certainly the entrepreneur with limited capital, wanting to enter the industry, will find the reverberatory furnace with its low first cost, and low emissions rate, the most practical approach to the choice of iron melting equipment.

The excess prepared molding sand system is expected to have relatively widespread effects on sand preparation in iron foundries since it seems to solve the ubiquitous problem of hot molding sand. Other potential modifications in non-melting applications are not expected to result in rapid changes in normal operating methods or emissions collection capability. Similarly no major technological breakthroughs in emissions control systems, other than those already discussed, are known at this time.

X - PROJECTION OF TRENDS

GROWTH OF THE IRON FOUNDRY INDUSTRY

The previous discussion in Section III, as well as Exhibits III-1 through III-6, presented the historical development of the iron foundry industry, particularly during the postwar period. The situation can be described as one in which the small, individually owned entrepreneurships which once characterized the industry, are rapidly ceasing to exist, and are being replaced by larger, corporately owned foundries, with an ever-increasing percentage of the latter being captive foundries. The growth of iron castings output, combined with the reduction in number of foundries by 50% in a period of less than 25 years, has resulted in more than doubling the average output per foundry.

It is particularly significant that the reduction in number of iron foundries has been almost entirely among the small-sized companies. While the medium- and large-sized foundries have remained relatively constant in number, the small foundries have declined to under half of their number during the postwar period. The reasons for this are not difficult to trace. The increasing costs of labor and the greater difficulty in recruiting and holding skilled foundry labor have resulted in a continuing increase in the degree of mechanization in foundries. It was once possible to operate a foundry on a very small investment in equipment, and to use the same crew to perform all of the functions of melting, molding, pouring, cleaning, etc. The modern foundry requires a high investment cost, with labor being fixed in single area jobs, necessitating relatively continuous operation of the shop.

To all of these problems, the additional consideration of environmental control is now being added. This generally requires the installation of relatively high cost air, water, noise, and other control systems, which further add to the capital and operating costs without, by themselves, contributing to production or earnings. This has caused many marginal operators to go out of business, and can be expected to continue to have this effect in the next decade. An analysis of the iron foundry population in the state of California during the postwar period has shown that the periods when strict enforcement of air pollution codes were introduced were also the periods of most rapid decline in the number of iron foundries.

The growth of production in the iron foundry industry has been projected by estimating the growth rates for each of the principal segments identified previously, based on the growth of the user industry identified with that segment. The three were then combined to provide the input for the total estimated growth. Total iron castings production, excluding ingot molds made from direct blast furnace iron, has been projected to be approximately 17 million tons per year by 1980, or an average of 2% increase per year.

Iron castings production growth, as measured by tons per year of output, has been somewhat behind the trends of some of the other industries, and has not kept up with the trends shown in the early 1950's. This has probably been caused, in part, by competition from other products and materials, such as steel weldments, nonferrous castings and nonmetallics. The relatively moderate increase in tonnage of output has also been caused by the improvement in technology which has enabled thinner wall iron castings to be produced, resulting in an increase in the number of castings per ton of weight. On a basis of quantity of castings, therefore, the growth of output of the iron foundry industry has more than kept up with the national gross product growth.

The number of iron foundries which will be in operation by 1980 has been projected to be approximately 1,100. Since the number of medium- and large-sized foundries has been projected to increase slightly, the entire drop from the 1969 total of 1,630 foundries to 1,100 foundries is expected to take place among the small-sized companies. The combination of increasing output and reduced number of producers is expected to continue to increase the average output per foundry to an estimated 16,500 tons per year by 1980. This is almost four times the average production immediately after the war.

EQUIPMENT TRENDS

The most significant changes in the types and uses of equipment which are expected to take place in the iron foundry are in the melting department. The cupola, which once was almost the only source of molten iron, has been rapidly declining in number of installations, with the number in 1969 being only about 45% of those in existence immediately after the war. This decline has been projected to continue at an undiminished rate, with the number of cupolas in 1980 estimated to be about 1,300. Although part of this decline has been traced directly to the reduction in the number of small-sized foundries, it has also been related to several other factors. The principal one has been the replacement of the cupola by other methods of melting, electric arc, electric induction, and fuel fired reverberatory furnaces. An additional factor has been the replacement, in many foundries, of two or more cupolas by a single, larger-sized unit.

In 1969, an estimated 85% of all iron melted in iron foundries was performed in cupolas. As the replacement of cupolas by other forms of melting continues to accelerate, the amount of iron melted in cupolas will decrease, with the amount by 1980 projected to be as low as 50% of the total. The electric methods of melting, both direct arc and induction, will account for almost 50%, with the small remainder being melted in fuel fired, reverberatory furnaces.

The electric arc furnace population has been projected to be about 350 units by 1980. Electric induction furnaces have been projected to total about 1,350 units both coreless and channel types, by 1980. Reverberatory furnaces have been estimated to increase to about 250 units by 1980. All of these types of furnaces can be used for holding, duplexing and superheating, as well as for melting of iron. Therefore, the total of 1,950 furnace units other than cupolas is not to be considered entirely as replacements for cupola melting. In fact, probably as much as one-third of them will not be used for melting, but will perform the other functions of holding, duplexing and superheating.

Although the tonnage of malleable iron which is produced has remained relatively constant, the number of reverberatory air furnaces used for duplexing has been declining steadily, as these types of fuel fired furnaces have been replaced by electric furnaces, principally arc furnaces. On the other hand, the tonnage of ductile iron has been increasing every year, and is expected to be about double the 1969 tonnage by 1980. This will result in a corresponding increase in the amount of magnesium treatment of iron which will be performed.

The trend toward mechanization of molding, pouring and shakeout lines has been continuing at an increasing rate. Most of the large- and medium-sized foundries employ some degree of mechanized molding. With the development of dependable and economical automated molding systems for small-sized molds, many of the small foundries have installed mechanized lines. Similarly, there are an increasing number of foundries in which continuous and automated sand handling and preparation systems have been installed. There is every reason to believe that within the next 10 years, the majority of iron foundries will use some form of mechanized molding, pouring, shakeout and sand preparation.

Coremaking has also been undergoing a technological change, with the trend being away from oil-bonded, baked sand cores, toward chemically bonded, thermally cured and air cured cores. Core processing is becoming mechanized and automated. Fuel fired core ovens are being replaced with dielectric ovens, or with processes in which cores are cured directly in the core boxes.

The entire area of handling and preparation of materials used in the foundry is continually being reviewed with respect to the effect on emissions production and economy of collection. Iron foundries are being more selective in purchasing of scrap, with more attention being given to elimination of combustible materials from the scrap before purchase. Larger foundries are installing scrap preparation facilities involving pre-burning or cleaning to remove materials which will produce emissions during melting. Screening of coke and stone, and use of higher quality briquettes are recognized as a means of eliminating fines which will tend to blow out of furnaces during melting.

It is believed that the next generation will see an increasing trend toward centralized scrap preparation yards which will service many iron foundries in a given area. This will help to provide cleaner scrap at lower costs.

EFFECTS ON EMISSIONS

Many of the trends toward electric or fuel fired melting furnaces, mechanized molding, and continuous sand preparation systems will have important effects in reducing the quantity of emissions produced, or in making the emissions easier or less costly to collect. The decisions made in selecting new equipment are, therefore, being made to an increasing degree with reference to the effect on reduction of emissions, or on economy of emissions collection.

The use of a greater amount of pre-cleaned or burned scrap will reduce the quantity of emissions from combustibles now charged into furnaces along with the scrap. Screening to remove fines will also help to accomplish this same goal.

The trend away from cupola melting and toward electric or fuel fired melting furnaces will have a significant effect in reducing emissions. The electric induction furnaces and the fuel fired reverberatory furnaces produce a very small quantity of emissions. The electric arc furnace emissions are substantial in quantity, but are much easier and more economical to collect than are cupola emissions.

The mechanization of molding, pouring, shakeout and sand preparation facilities has not reduced the quantities of emissions which are produced, but has resulted in confining their production to fixed locations. Thus, it is relatively simple in many cases to construct enclosures which can be used as a means of collection of emissions with a minimum of infiltrated air. This not only reduces the size and cost of the collection system, but makes it more effective, reducing the amount of unconfined emissions which are released in the foundry building.

XI - DEFINITION OF THE IRON FOUNDRY AIR POLLUTION PROBLEM

GENERAL

The widespread distribution of iron foundries and the prominence of the cupola stack in most communities in which an iron foundry is located have combined to label the iron foundry as a major source of air pollution. This opinion is often strongly held by the downwind neighbors of a foundry using an uncontrolled cupola for iron melting, and air pollution control bodies receiving complaints of foundry emissions.

It is estimated that 243,000 tons per year of particulate matter are generated from iron foundry melting operations, of which about 182,000 tons are emitted to the atmosphere, the remainder being collected. In addition, 1,504,000 tons per year of particulate matter are estimated from non-melting operations of which about 77,000 tons are estimated to be emitted to the atmosphere. Total particulate emissions released to the atmosphere are therefore estimated at 259,000 tons per year. Based upon a 1968 inventory by NAPCA, of emissions from all sources, it is estimated that the iron foundry contributes about 3.5% of all particulate matter emitted by industrial sources, and about 0.9% of all particulate matter emitted by all sources.[1]

NATURE OF FOUNDRY EMISSIONS

Particulate and gaseous emissions result from most iron foundry operations, with the largest concentrations being emitted from cupola and direct electric arc furnace melting. Cupola emissions, as described earlier, include particulate matter such as coke particles and ash, metallic fume, smoke oil vapor, and dust from sand and limestone. Gaseous emissions from the cupola include carbon monoxide from incompletely burned coke, carbon dioxide, water vapor, nitrogen, and small amounts of sulfur dioxide and fluorine compounds. The last two emissions quickly hydrolize to form corrosive acids.

Electric arc furnace melting results in similar types of missions except for those deriving from the combustion of coke, and include metallic fume, oil vapor dust, and smoke and gaseous compounds from the combustible materials in the furnace charge. Emissions from reverberatory and electric induction furnaces are negligible, and control equipment is rarely employed on this equipment.

Drying and preheating cause emissions similar to the cupola except that the fuel most commonly used is natural gas instead of coke.

Many operations, such as sand handling, raw material storage and handling, charge makeup, molding and sand conditioning produce only mechanical dust emissions. This particulate matter is neither corrosive nor toxic, as some components of cupola emissions, nor an asphyxiant like carbon dioxide. A degree of hazard does exist however, from breathing the dust-laden air over extended periods of time. Similar mechanical dusts result from several cleaning operations including abrasive cleaning and grinding. These metallic dusts present quite the same kind of health hazards if completely uncontrolled.

The increased use in recent years of chemically bonded core and molding sands has given rise to an additional type of emission. Both the setting reactions and the combustion of the bonding material when the mold is poured result in smoke and gaseous emissions that can be unpleasant and mildly toxic.

A small percent of iron castings are painted before shipment. The process produces gaseous emissions consisting of thinners and, depending on the equipment used, paint spray.

Many foundries continue to use oil bonded cores requiring oven baking for setting. Gaseous emissions are produced consisting of the more volatile fractions of the core oil and some particulate matter such as smoke.

The adverse nature of these various particulate and gaseous emissions produced by foundry processes has long been recognized. Furthermore, to the distinct credit of the industry, much has been accomplished through the years to control emissions and to improve both the foundry and atmospheric environment. It is also important to note that efforts in this direction were begun many years before air pollution concerns achieved national prominence.

It has been stated earlier that control devices for cupolas were in use as early as 1938, and efforts to control nonmelting processes date back at least to the 1920's. While early equipment was crude and only partly effective, industry pressure has resulted in steady improvement in efficiency and more widespread use of control equipment.

INVENTORY OF FOUNDRY EMISSIONS

The analysis of cupola and electric furnace emissions and the factors affecting the rates of emissions showed that an average of 20.8 pounds of particulate emissions are produced per ton of metal melted in an iron foundry cupola, and that an average of 13.8 pounds of particulate emissions per ton of metal melted result from direct electric arc furnace iron production.

Exhibit XI-1 shows the total estimated particulate emissions generated by melting operations in foundries using cupolas and direct electric arc furnaces in 1969. The exhibit shows total quantities for each of nine geographical regions and the nationwide totals based on the molten iron production for the year and the above emission rates. Based on a survey of iron foundries, considering the number and capacity of furnaces equipped with control systems, the effectiveness of the control systems, and the number of uncontrolled furnaces, it is estimated that 75% of the particulate emissions generated are presently being released to the atmosphere.

Exhibit XI-1 also shows estimated quantities of carbon monoxide generated and emitted. The first estimate is based on an average cupola operating with a 7/1 coke ratio, using coke with a carbon content of 91%, and with 11.6% carbon monoxide in the top gas. Under these conditions, 276 pounds of carbon monoxide is generated per ton of metal melted.

The amount of carbon monoxide emitted to the atmosphere is dependent on a number of factors including the temperature of the top gas, the availability of infiltrated air to provide oxygen for combustion, the completeness of combustion, and the percent of the total time that burning of the carbon monoxide occurs. With sufficient oxygen from the infiltrated air and with constant combustion, the carbon monoxide content should be completely burned. Several factors tend to work against this ideal condition, including the flame being extinguished by each charge addition, lack of immediate re-ignition either without an afterburner, or with an improperly directed flame from an afterburner, varying carbon monoxide content precluding constant combustion, and variable air supply. A conservative estimate of 50% combustion efficiency has been applied to the quantities of total carbon monoxide generated to obtain the estimated weight of this gas emitted into the atmosphere.

The results of the calculations can be summarized as follows for 1969 nationwide production levels:

Total castings produced	16,614,000 Tons
Total molten iron produced	24,367,000 Tons
Total particulate emissions generated	243,000 Tons
Total carbon monoxide generated	2,924,000 Tons
Total particulate emissions emitted	182,000 Tons
Total carbon monoxide emitted	1,462,000 Tons

Particulates small enough to remain suspended in air over an extended period are defined as aerosols. The maximum diameter of such particles has been variously identified as from 20 to 100 microns. Using 50 microns as a limiting diameter, the aerosols resulting from iron melting operations amount to approximately 56% by weight of the total emissions generated. On this basis, the suspendible particulate matter generated by melting operations in 1969 amounted to 136,000 tons, of which approximately 102,000 tons was emitted to the atmosphere. Particulates over 50 microns diameter, totaling 80,000 tons for 1969, being too large to remain suspended, settled out in a short time depending on meteorological conditions.

The above data are derived only from cupola and electric arc furnace operation. Emissions from other melting equipment including induction furnaces and reverberatory furnaces are negligible, not only because of conditions inherent to these types of furnaces but also because generally cleaner scrap metal is used for furnace charges and a relatively small percentage of the total iron is melted in these furnaces. Preheating of less clean scrap for charging into induction furnaces will add significantly to the emissions inventory only when the process is substantially more widely used than it is now. At its present level of application, preheater emissions are also negligible.

Emissions previously described from non-melting foundry processes, with a single important exception, are often controlled as a standard practice, generally affect only the foundry environment, and are released to the atmosphere only in minor quantities compared to cupola and electric arc furnace emissions. The concentration of these emissions at their source can be substantial as in the case of the shakeout, abrasive cleaning, and griding, but the particles emitted are often large with a relatively high settling rate. The portion of the particulate matter escaping the normal collection ductwork tends to settle out within the foundry building.

An analysis of non-melting operations indicates that 114.91 pounds of emissions are generated for each ton of metal melted, but that only 5.83 pounds of this total are released to the atmosphere. Normal collection practices and settling out within the foundry building account for the difference between these two quantities. Exhibit XI-2 shows the total estimated quantities generated and emitted to the atmosphere for the same nine geographical regions tabulated in Exhibit XI-1. The total estimated weight of non-melting suspendible emissions from non-melting operations in 1969 is shown in the exhibit to be 76,600 tons.

The non-melting emissions posing the greatest current problem are those resulting from coremaking. A minor problem existed in the past when practically all cores were made from oil sand. This type of core, however, is thermally cured in a core oven, and the emissions are relatively easy to capture from the core oven stack for afterburning. The use of organic chemical bonding agents, that are becoming more and more widely used, intensifies the problem since these produce emissions extremely difficult to capture due to their method of application.

Molds or cores made from air set sand are often set out on foundry floor or on racks while the sand sets. The local environment in this situation is extremely poor. Not only is it difficult to capture the emissions over a large floor area, but the dilution of the gaseous emissions by the air makes the resulting mixture difficult and expensive to burn in any type of afterburner.

The situation in many foundries for thermally cured chemical binders when making shell or hot box cores causes similar problems for the local environment as well as afterburning. The resulting odors can be detected beyond the foundry property in many cases.

INDUSTRY PROBLEMS

The air pollution laws established in recent years have created many serious problems for the iron foundry industry beyond the determination of the proper emission control equipment to insure compliance with local codes.

Code limitations on permissible emissions are anything but static. More than a few foundries have invested substantial amounts of capital in equipment to meet the first generation codes, only to discover, a short time later, that restrictions have been made more severe, requiring costly reworking of the control equipment. Current codes do not limit gaseous emissions but all foundry owners are fearful that stringent limitations on carbon monoxide, sulfur dioxide and other gases are forthcoming in the near future. These conditions mean that the equipment purchased now must not only insure compliance with present laws but also with future laws not yet drafted, or at the very least, must be flexible enough to permit upgrading in the future.

The emission control system has been characterized as a profit-sharing silent partner that adds nothing to the value of the foundry product but continually demands its share of the profit. This is an unwelcome situation at best for the large financially secure production foundry. It can be extremely serious for the typically small, privately owned foundry with low profitability and with cash-flow problems. For these reasons many foundries have been slow to react to the need for emission controls. In some states, a minor form of relief is granted by waiving sales taxes on purchases of equipment for air and water pollution control. However, other assistance and incentive programs in terms of tax relief, faster write-offs, low interest loans, assistance grants, and similar approaches are necessary to promote rapid and complete compliance without forcing the smaller firms out of business. A national program applying uniform standards in all areas that will aid all foundries in installing emission control systems is required. The development of a suitable program requires additional study.

State air pollution control laws vary widely in the methods of determining permissible emissions from foundries. One of the methods becoming more widely used is the process weight basis in which permissible emissions are related to the total weight of all materials except air introduced into the furnace for a given time span. Some codes differentiate between existing furnaces and new furnaces, or between jobbing foundries and production foundries, and specify different permissible emission rates for each. Few of the codes, however, differentiate between foundries that may have the same process weight per hour but operate widely different total hours a week. Thus the small foundry melting only 10 hours a week requires the same size and type of control system as another foundry with the same size cupola, but is melting 80 hours a week. The financial impact of such a relationship can be seen in the cost per ton curves and summary of operating costs given in the exhibits for Section VIII. The economic burden of a fabric filter for cupolas, with identical process weights of 15 ton per hour, for example, but operating at 1,000 and 4,000 hours per year can be seen on Exhibit VIII-32 to be $4 per ton and $1.33 per ton respectively.

It is evident that application of the same process weight standard is not an equitable method and that consideration should be given to the use of a longer time span than one hour. Additional study would be required to develop a more reasonable and equitable basis for applying process weight standards.

Despite the rapid technological advances in emissions control techniques and equipment in the past few years, a gap still exists between foundry needs and equipment to meet those needs efficiently and at a cost the foundry industry can afford to pay.

With improvements in emission control capability desired for each operation in all foundry departments, a basis for establishing a degree of need and a priority ranking for research and development projects is obvious. Page one of Exhibit XI-3 presents a matrix listing the major emissions-producing operations versus the important characteristics of the emissions and the control equipment installation required for suitable control. Page two of the exhibit shows the rating code appropriate for each characteristic, and the priority assigned to each of three ranges of the total rating for each operation. The operations indicating the greatest need, and therefore the highest priority, are cupola melting and coremaking. Research and development projects for improving emission control capabilities in these areas are included in recommendations developed in the following section.

REFERENCES

1. Nationwide Inventory of Air Pollutant Emissions, 1968, U.S. Department of Health, Education, and Welfare, Public Health Service, Environmental Health Service, Publication No. AP-73.

XII - OPPORTUNITIES FOR RESEARCH AND DEVELOPMENT

NEEDS FOR RESEARCH AND DEVELOPMENT

Although iron founding has been carried on for thousands of years, the application of emission control techniques have only been made in iron foundries for some 30 years. Nevertheless, in those few years, the techniques and equipment have been improved to the point where it can now be reasonably stated that means exist for emission control for practically all iron foundry operations. However, in many cases, these emission control methods or equipment are not economical to install and operate, making their use economically prohibitive, particularly in small foundries. The needs for research and development for emission control in the iron foundry industry are therefore largely economically oriented, aimed at providing equipment and methods which can be used by all sizes of foundries without forcing them out of business.

Fundamental Knowledge

Much of the presently used control equipment was adapted from other industrial uses, or was developed with little or no knowledge of the fundamentals of emission evolution and the nature of the emissions. It is believed that more basic understanding of these phenomena will provide necessary input for development of more efficient and economical means for controlling emissions.

The results of the regression analysis which was conducted as a part of this investigation clearly demonstrated the lack of quantitative data which related emissions to cupola design and operating features. Additionally, the data which were collected from stack tests on cupolas also demonstrated the lack of correlation which results when the testing is not done under controlled conditions, in which all facts relating emissions produced with operating factors and charge material variations are not clearly recorded. The research programs which are discussed are therefore proposed to be performed by qualified laboratories under controlled conditions. Among the questions which must be answered are the following:

1. What are the basic relationships between melting furnace design and operating features, and the production and evolution of emissions?
2. What are the mechanisms by which very fine metallic oxides are formed, and what variables affect their formation?
3. What causes iron oxide formation, and what variables affect rate and quantity of production?

Economic Factors

The economic factors involving emission control have been shown to be the most important area for further research and development, particularly if methods are to be developed which can be applied to small foundries and at the same time permit them to survive. Research and development efforts are needed to answer the following questions.

1. What can be done to reduce costs of collection of fine particles?

2. What means can be developed to reduce costs of installation and operation of dust collection systems?

3. What means can be developed to economically utilize waste heat in cupola stack gases?

4. Can uses be found for collected waste materials which will aid in improvement of economy of collection?

Materials

1. Can fabric materials be developed for fabric filter collectors which will resist high temperatures and corrosive gases, and at the same time not be excessively costly?

2. Can core binder materials be developed which will not evolve acrid and noxious fumes during curing?

Processes

What alternates can be developed for cupola melting which will combine continuous operation with economy of melting and low emissions production?

ONGOING RESEARCH AND DEVELOPMENT PROJECTS

Various research and development projects, covering a number of aspects of iron foundry facilities and operation, have been publicized or are known to be in progress. Since many companies do not publicize their research and development activities, there are undoubtedly other projects which are now in progress but which have not been made known to the industry. Among the known projects, some of which were discussed in earlier sections of this study, are the following.

Melting of Iron

1. A reverse draft, or what has been referred to as an "upside-down cupola," has been developed by Mechanite Metals Co. and is now in experimental operation at Combustion Engineering Company's Monogahela foundry. The intent of this cupola is to reduce emissions evolution by forcing the blast air downward through the cupola burden.

2. A continuous, gas fired shaft furnace for melting of iron has been developed by Battelle Memorial Institute and is in experimental operation at the Cooper-Bessemer Company foundry. The purpose of the furnace is to provide economical, low emission melting of iron.

3. A continuous, induction heated melting furnace for iron has been developed by Ajax Magnethermic Corp. and General Motors Corp., for the purpose of providing low emission, economical melting of iron.

4. A gas injection program on a cupola is being conducted jointly by Battelle Memorial Institute and Campbell, Wyant and Cannon at their foundry in Muskegon. The purpose is to provide greater economy in melting, reduced coke consumption,

and possibly reduced emissions. Similar programs are also being conducted in other iron foundries in the United States and in Europe.

Emissions Collection

1. A new high temperature fabric with a new fabric filter collector design is being developed by a commercial foundry.

2. A new type of sand bed dust collector is being developed by the Lurgi Company in Germany.

3. A new type of dust collector utilizing a rain of sand to collect dust and heat, and also to transfer the heat to combustion blast air, has been developed by Butler and Kutny.

4. A collection system utilizing the heat of combustion of the cupola gases to preheat blast air has been developed by Holley, Kenney & Schott and is in operation at Majestic Iron Works foundry.

5. A new low cost method of wet collection of fine particles is reported to be in development by National Dust Collector Co.

6. A program of waste product utilization has been conducted by Zoller Castings Company, in which collected cupola dust has been used as a fertilizer.

PROPOSED RESEARCH AND DEVELOPMENT PROJECTS

Based on the needs for research and development as previously described, the ongoing projects, and the gap which exists between available technology and needs, a series of potential research and development projects has been assembled and is described in the following paragraphs. These projects have also been summarized in Exhibit XII-1. The projects have been grouped into associated programs involving fundamental research, materials and equipment development, economic improvements, and standards development. A priority rating has been applied to each project. However, because of the previously noted fact that control technology and equipment actually are available for almost every iron foundry source of emissions, although not always at economical conditions, none of the programs has been rated as highest or urgent priority.

Estimated costs have also been applied to each project. In general, they were based on the work being performed by a research institute, university, or industrial research department. The actual costs of research projects are difficult to determine with any accuracy. The costs given are, therefore, intended only as order-of-magnitude figures to enable an assessment to be made of the relative value of benefit of each project to the projected cost.

Fundamental Research Projects

Project Nos. 1, 2 and 3 are a series of related programs, involving research into the relationships which exist between the quantity and type of emissions which are produced in the cupola process, and the variables of design, operation and raw materials used. These programs are proposed to be carried out on an experimental cupola by a qualified research institute or a university with an experimental foundry. They can also be carried out in a commercial foundry if a cupola can be set aside for the work.

No. 1. Stack Sampling Program

The first project involves a controlled stack sampling program on a cupola to determine the effect of cupola design, operating and raw material variables on the type and quantity of emissions which are produced. The goal of the program will be to provide quantitative information, which is not now available to enable designers of cupolas and emission controls as well as foundry operators, to optimize design and operating variables, to result in production of a minimum amount of emissions and to make them easier to collect. The stack sampling must be accomplished under controlled conditions in which the various design, operating and raw materials factors can be individually varied, and the effects on emissions noted. A program of from six months to one year in duration is believed to be required to accomplish the desired results. The cost of such a program, including a team of three or four investigators, cupola equipment, test apparatus, and raw materials, is estimated to be in the range of $150,000 to $200,000. A top level priority has been assigned to this program with relationship to the other recommended iron foundry programs, since it is fundamental in nature and needed to carry out other recommended work. There is no known research which is being carried out in this area.

No. 2. Iron Oxide Formation Program

The second project is an extension of the stack sampling program and probably should be carried out by the same researchers. The purpose of the work will be to conduct research which will determine the mechanism of iron oxide formation in the cupola, and the effect of operating and raw materials variables on the quantity of iron oxide which was formed. Exhibit VI-14 suggested a possible relationship between the type of scrap used and the potential amount of iron oxide which is present. This should be confirmed in the proposed research program. The work has been estimated to be able to be carried out in a period of four to six months by a team of three researchers. The estimated cost of such a program, including cost of the team, the experimental cupola, test apparatus and raw materials, is in the range of $50,000 to $75,000. A medium level priority has been assigned to this work, which should be valuable in potentially reducing the amount of iron oxide present in cupola emissions. There is no known research which is being carried out in this area.

No. 3. Fine Oxide-Opacity Relationship Program

The third program is an extension of both the stack sampling program and the research into iron oxide formation, and also can be carried out by the same researchers. The purpose of the work will be to establish a relationship between the presence of fine metallic oxides in cupola stack gases and the opacity of the gases. The results of this program can be used to develop new opacity test standards which can more effectively be used as a means of measurement of emissions levels than the presently used Ringelmann chart. The time required for this work has been estimated to be three to four months, using a staff of two. The estimated cost for the work, including the research team, raw materials and test apparatus is in the range of $50,000 to $75,000. There is no known research which is being carried out in this area.

The total fundamental research programs which have been proposed can be combined into a single program to be conducted by the same organization. If this is done, the work could be accomplished in about a year with a team of about six researchers, at a cost in the range of $200,000 to $300,000.

Economic Research Projects

We have previously noted that the principal area in which new development work remains to be done involves the economic effect of emission control on foundry costs. Rigid enforcement of present control standards, combined with necessity of using existing designs of equipment, would have the effect of forcing many of the smaller sized foundries out of business, and seriously affecting the earnings of medium and even large-sized foundries. The group of programs included in the economic area includes a variety of approaches to the problem, involving improved raw materials, waste heat and waste product utilization, and reduced costs of collection.

No. 5 Waste Heat Utilization

The purpose of a development project for greater utilization of waste heat in cupola stack gases is to improve the economics of cupola melting and emission control. Two potential sources of heat energy are proposed to be investigated. The first covers the sensible heat in the hot cupola stack gases, which is in the range of 180 to 320 BTU per pound of gas, while the second covers the heat of combustion of the CO in the stack gas, which is in the range of 4,350 to 8,700 BTU per pound of gas. The work is proposed to be accomplished by a research institute, or by a builder of melting or emission control equipment. A program of about six months' duration involving a staff of three researchers is proposed to investigate past attempts at waste heat utilization, evaluate them, and develop a new method which will combine sensible heat and heat of combustion recovery. The estimated cost of such a program is in the range of \$100,000 to \$150,000. The benefit will be achieved by reduced coke consumption during melting, which will also reduce costs of melting and reduce emissions levels from the cupola. Although the waste heat recuperator, utilizing the Griffin system, was commonly used in cupola installations more than 20 years ago, the high costs of maintenance and low reliability have made it obsolete. Known development programs include a proposed system for cleaning gases and recuperation of heat by use of a sand stream through which the gases pass[1] and a combination gas scrubber and combustion unit for preheating air.[2]

No. 7. Centralized Scrap Preparation Development

The high costs of scrap preparation, with particular reference to removal of combustibles and nonferrous metals, has resulted in poorly prepared scrap being used in many foundries. The purpose of the proposed development project is to enable a centralized scrap preparation facility to be installed in a community, serving numerous iron foundries and providing properly prepared scrap of minimum cost. This will promote use of this scrap and will result in reduced emissions from melting operations. This program can be carried out by an engineering firm, or by a large scrap metal organization. A three to four month study using a team of two engineers is proposed, at an estimated cost of \$30,000 to \$50,000. A medium level priority has been assigned to this project. No known work is now being carried out in this area. However, a study was made by the U. S. Bureau of Mines on dismantling of junk automobiles to produce quality scrap.[3]

No. 10. Waste Product Utilization

At present, the collected emissions from iron foundry operations are not utilized for any purpose of value other than for landfill and, in fact, are costly to remove from foundry sites for disposition. The purpose of this proposed project is to develop potential uses for these waste products which may help pay for the costs of collection and may even provide some revenue. The development project would consist of an investigation into past and present attemps to utilize waste products from iron foundries and similar industries, an investigation of the analysis of typical waste products, and the development of potential uses for these products. This work is proposed to be carried out by a research institute, a university, or an engineering company. A program of three to four months' duration utilizing a staff of one or two investigators is envisioned, at an estimated cost of $20,000 to $30,000. Because of the marginal possibility of a positive result, a low level of priority has been assigned to this project. Development work in this area has been carried out by the Zoller Castings Company, which has used collected emissions as fertilizer on farmland, and by Swindell Dressler Co., which has conducted a study on the use of steel plant wastes.[4]

Materials Development Projects

In certain areas involving evolution or collection of emissions in the iron foundry, equipment exists for the required purpose, but optimum materials have not yet been developed to make use of known equipment or techniques. The projects in this group are directed toward development of new or improved materials.

No. 4. High Temperature Fabric

Fabric filter collectors are known to be the most efficient means of emissions control. However, their use in melting operations has been limited, and their cost of operation has been increased by the lack of availability of fabric materials which will resist high temperatures over 500^{o} F and at the same time resist the corrosive action of stack gases which result from use of fluorspar in the cupola charge. A program of development of temperature and corrosion-resistant fabrics, related if necessary to changed design of the baghouse collector system, is proposed. Such a new material will result in an increased utilization and reduced cost of operating fabric filter collectors. This work can be carried out by a research institute, or a manufacturer of fabric materials. The program has been estimated to involve at least six months, using a staff of three researchers, with appropriate test equipment. The cost has been estimated to be in the range of $75,000 to $100,000. Because of existence of several research projects in this area, a medium level priority has been assigned. Known development work is being carried out by a research company and a manufacturer on a new fabric material combined with a new collector design. Additional work has been conducted by NAPCA on endurance tests of high temperature fabrics,[5] and endurance tests on fiber glass fabrics.[6]

No. 8. Low Emission Core Binder Materials

The preparation of oil bonded sand cores, which were cured in an oven, results in oil fumes which are relatively easy to capture, and which can be incinerated by use of a catalytic combustion unit. However, the increasing use of chemically bonded core materials which are cured in the molds or on racks without use of an oven, produces fumes which are difficult to capture, are acrid and often toxic in nature, and which are difficult to convert into harmless, odorless gases. The proposed research program involves the development of new core binder materials which produce the desired physical properties in cores and which do not give off noxious fumes during curing. The goal of the work will be to eliminate the fumes which are generally associated with coremaking operations and with subsequent pouring of molds. This work is proposed to be performed by a research institute, or by a manufacturer of chemicals used in cores. A six-month program involving three researchers at an estimated cost of $100,000 to $150,000 has been envisaged. A medium priority level has been assigned to this work. Although no research programs in this area have been reported, it is believed that some of the manufacturers of core additive materials are engaged in such work.

Development of New Equipment

The principal area of new equipment development is in melting of iron, with specific reference to replacement of the cupola by other melting methods which will still provide some of the desirable features of the cupola, without some of the undesirable features. The important other area for new equipment development is in new dust collection systems of lower cost and higher efficiency. Two such areas have been selected for proposed research and development projects.

No. 6. Continuous Melting Furnace

The principal advantages of the cupola for iron melting are that it is a continuous melter and an economical melter, and it is capable of using a wide variety of metallic charge materials. The principal disadvantage, which has been well documented in this study, is that it produces a large quantity of emissions which are difficult and costly to collect. The alternate methods of melting which are now in use--electric arc, induction and reverberatory are all batch-type melters and, with the exception of the electric arc, are not capable of using a wide range of metal scrap in the charge. The proposed development project involves the design and construction of a continuous, fuel fired or electrically heated, melting furnace, which will be economical to operate, and which will produce a low level of emissions. It should also be capable of being built and installed for a relatively low costs. The benefits of such a furnace will be largely felt by the smaller foundries which are now faced with the combination of high cost melting and emission control installations. The development program can be best carried out by a research institute, a furnace builder, or a large foundry with a development department. A program of up to one year, utilizing a staff of four people, at an estimated cost of $200,000 to $300,000 is believed to be necessary. In view of known research now being carried out in this field, a medium level of priority has been assigned to the project. Two projects of this type are known to exist. The first involves a joint development by Battelle Memorial Institute and Cooper Bessemer Co., covering a gas fired, vertical shaft furnace. The second involves General Motors Corp. and Ajax Magnethermic Corp. and covers a continuous induction heated melting furnance.[7]

No. 9. Agglomeration of Fine Emissions

The cost of emission control, particularly on melting operations, increases rapidly as the particle size to be captured decreases. Submicron sized particles are very costly to collect, requiring high pressure-drop wet scrubbers, baghouses or electrostatic precipitators. However, if it were possible to agglomerate fine particles into coarse particles, efficiency of collection could be improved, and collection costs could be reduced. The proposed projects is directed toward the development of a means of agglomeration of fine particles into coarse particles, using sonic or electrical means for accomplishing this. This work can be accomplished by a research institute, or by the development laboratory of an emission control equipment builder. A project involving five to six months of time, utilizing a staff of three, at an estimated cost of $75,000 to $100,000 has been contemplated. A low level of priority has been assigned to this work. No known research is being carried out in this field.

REFERENCE

1. Butler, Kutny, "A New Approach for Cupola Emission Control," Modern Casting, June, 1970.

2. "Cupola Off-Gas Scrubbing with Recuperation", "33" Magazine, 1969.

3. Dean, "Dismantling a Typical Junk Automobile to Produce Quality Scrap," Bureau of Mines, No. 2350, December, 1969.

4. M. A. Osman, "Preparation of Useful Products from Steel Plant Dusts," Swindell-Dressler Company, 1969.

5. J. M. Yacher, "High Temperature Fabric Filter Study," NAPCA, 1969-70.

6. Spaite, Harrington, "Endurance of Fiberglass Filter Fabrics," Napca, 1967.

7. Amala, Walker, "Continuous Induction Iron Melting," A.F.S. Transactions, 1970.